A MANUAL

OF

TELEGRAPH CONSTRUCTION.

SCIENTIFIC WORKS

BY

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A MANUAL

OF

TELEGRAPH CONSTRUCTION:

THE MECHANICAL ELEMENTS

OF

ELECTRIC TELEGRAPH ENGINEERING.

BY

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Second Edition, with Appendices.

PUBLISHED WITH THE APPROVAL OF THE DIRECTOR-GENERAL OF TELEGRAPHS IN INDIA.

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PREFACE TO THE FIRST EDITION.

A TELEGRAPH structure must fulfil two distinct sets of conditions, the Mechanical and the Electrical. On the subject of the latter there are many special Treatises, on the former this book is the first of its kind. The special Treatises on Telegraphy, with the exception of that of M. Blavier, do not treat of Mechanical principles, these being very justly regarded as distinct from the Electrical conditions, and their full exposition as out of place in a Treatise on the application of Electricity. Although the Mechanical principles and practice are common to other structures than Telegraphs, the particular case of a Telegraph structure requires separate treatment; for some of the materials employed and the functions of the structure are peculiar to Telegraph structures.

In no branch are the requirements of the Telegraph Engineer co-extensive with those of the Civil Engineer. Telegraph Engineering has several branches, as mast building, cable laying, &c., not pertaining to Civil Engineering, and Civil Engineering, again, includes many branches, as tunnelling, roads, railways, drainage, water supply, bridge building, &c., of no concern to the Telegraph Engineer. As examples may be instanced carpentry, brickwork, masonry, and earthwork :—the Telegraph Engineer has to join timbers in different ways, to make simple trusses, to build masts, &c.; but he is not concerned with very complex frames, roofs, &c., and is not called upon to execute extensive works in brick or cut stone. On the other hand, it is necessary that he should know the principles on which such

are built, to enable him to construct plinths of stone and of brick with stone copes, and to fasten posts, cantilevers, &c., on and in work built by others. The ordinary mode of embanking employed by the Engineer is inadmissible in Telegraph Engineering, for in the latter case the bank is always small in content, and is required to be of the best possible quality; the deepest excavation the Telegraph Engineer has to make seldom exceeds 12 feet, but it has frequently to be made in bad soil, on the edge of a river, and with very indifferent appliances. In general, when the Telegraph Engineer has difficult work to perform, the cost of the work and the distance over which it is distributed are such that the appliances commonly used by the Civil Engineer are not available; hence the great importance of a knowledge of principles in order to admit of the means at command being duly utilised, and the work carried out with safety, economy, and rapidity. I have dealt particularly with principles, because, these being known, the manner of their application must depend in a great measure on local circumstances. I hope the general adherence to this plan may render the work useful to the several Administrations, however widely their practice may differ, and the Paragraphs, being numbered, may be readily referred to in official instructions.

While thus assigning a prominent place to *General Principles*, I trust it will be found that the *practical* part of the subject has not been neglected, since I have endeavoured to supplement my own experience gained in India by a minute examination of the Telegraph systems of France and England, and of the principal processes of manufacture. I am indebted to the Director-General of Telegraphs in India for permission to use the official orders, &c., of his Department, to the Secretary to the Postal Department in England, and to the Director-in-Chief of the French Administration. My thanks are due to the Engineers of the English and French Administrations for their assistance, and also to several Engineering firms for infor-

mation and facilities for observing processes and operations as actually carried on at present, in particular to Messrs. Siemens, Brothers, Messrs. Hooper & Co., Mr. Henly, and Messrs. Laird, Brothers.

In writing the articles on Statics, Dynamics, Force, and Equilibrium and Stability, I have used the works of Baker, Blavier, Gregory Goodwin, Moseley, Poncelet, Poisson, Poinsot, Rankine, Stoney, Sheilds, Todhunter, Thomson and Tait, Weisbach, Whewell, Warr, and T. Young. In the section on Friction I have referred to the works of Morin and Jellett in addition. In the chapter on the Strength of Materials I have used principally the labours, literary and experimental, of Anderson, Barlow, Clay, Fairbairn, Hodgkinson, Tredgold, Kirkaldy, Morin, Navier, Gauthey, Poncelet, Prud'homme, Rankine, Rondelet, Vicat, and Pasley. For the chapter on Wood I have referred principally to the works of Tredgold, Tarbuck, Nicholson, and Newland. I am indebted to Mr. Kipping's work for much information on Wooden Masts, and to the works of Grantham and Reed for some hints on Mast Building in Iron. On Iron Construction I have referred to the works of Fairbairn, E. Clark, Campin, Kirkaldy, Tredgold, Hodgkinson, Clay, Morin, Rankine, Sheilds, Unwin, Truran, W. Vos Picket, and others. For the chapter on Insulators I have used the articles in the Chemical Dictionaries of Watts and Wurtz, the volume by M. P. Desmoreux in the Ency. Roret, the Dictionaries of Ure and Tomlinson, the Records of the Patents Office, the Report of the Committee on Cables, &c. For references on Botany I have used Professor Balfour's works. The section on Estimating is in general terms that employed in India. It was devised by accountants and executive officials on consultation, and appears admirably suited to the purposes for which such a system is required. For the section on the lifting of Heavy Bodies I have referred to Mr. Glyn's book on Cranes, and for the section on Mechanical Manipulation to Mr. Holtzapffel's work on the subject. I have

preferred ordinary language to Mathematical Formulæ whenever applicable. I have referred to many general works on Engineering, as D. Stevenson on Engineering in N. America, the works of Mr. W. Humber, the Dictionaries and Cyclopædias of Spon, Appleton, Nicholson, and Cresy; the Encyclopædias Britannica and Metropolitana, Nichol's Cyclopædia, and the English Cyclopædia. I have used several Engineers' Handbooks, the "*Engineering*" Journal, and am much indebted to the *Journal of the Society of Telegraph Engineers,* in particular to a resumé on Cables by Professor Fleeming-Jenkin. I have referred to several official pamphlets by Captain Mallock, and to Mr. Cappet's report on the Prussian Telegraphs.

J. CHRISTIE DOUGLAS.

LONDON, *November*, 1874.

NOTE TO THE SECOND EDITION.

IN the present Edition the author has endeavoured to furnish such additional information as the progress of Science has rendered necessary since the first publication of the work; and has added a copious Index, which he trusts will be found useful.

The new matter in the APPENDICES is based on data gathered from many different sources, official and private. The particulars of the Underground Line between Berlin and Halle were obligingly supplied by the Direction of the Imperial Telegraph Department, and many details of the Indian River Crossings by Major J. Eckford, Officiating Director of Construction, to whom, as well as to all who have kindly assisted him in rendering his work more complete, the author's best thanks are due.

CALCUTTA, *August*, 1877.

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ERRATA.

Page 59, Art. 118, lines 1 and 2, *for* "two forces," *read* "three forces."

Page 332, 13th line from bottom, *for* "in the tie," *read* "for the tie."

Page 355, 3rd line from bottom, *for* "calculations," *read* "calculation."

Pages 231, 232, 233, 234, and 245, Mr. Culley's name has been inadvertently misprinted.

PART I.

GENERAL PRINCIPLES OF STRENGTH AND STABILITY.

CHAPTER I.

FORCES, COUPLES, AND WORK.

SECTION I.—*Units of Force—Forces and Couples considered Statically.*

1. FORCE is an action between two bodies, either causing or tending to cause, change in their relative rest or motion. The direction of a force is that of the motion it tends to produce. Two forces are equal when being applied to the same body in opposite directions, their combined action produces no change in its rest or motion; when two or more forces acting on a body simultaneously produce no such change, the forces are said to be *in equilibrio* or balanced. The relations of a force to one of the bodies between which it acts is made known when three conditions respecting it are given—viz., the point of application or part of the body to which it is applied, the direction of its action, and its magnitude. When motion is not actually produced, but the forces are balanced, they are the subject of STATICS; when the motion is actually produced, or its production contemplated, the forces form the subject of DYNAMICS. Statics and dynamics are abstract mathematical sciences; and therefore, to attain rigidity and simplicity in demonstration, it is necessary to assume conditions which have no existence in fact; thus, bodies are assumed to be absolutely rigid and (unless otherwise stated) to be without weight, cords are assumed to be perfectly flexible and inextensible, and forces are assumed to act on mathematical points and in mathematical lines. As in considering balanced forces velocity and time have not to be considered, statics is simpler than dynamics, and is hence properly considered earlier. The mechanical principles involved in the efficiency and permanence of engineering structures mostly refer to balanced forces, but knowledge of the principles of dynamics is essential to render intelligible the effects of motion in producing shocks, the measurement of forces, &c.

2. The statical measure of a force is another force which will balance it; the dynamical measure is the quantity of motion it produces, or tends to produce, in a unit of time. A unit force is that force which, acting on a national standard unit of matter during the unit of time, generates the unit of velocity; this is termed Gauss' absolute unit, the term "absolute" being used to distinguish it from standards of force founded on the force of gravity, and therefore not absolute, but differing in value at different points on the earth's surface. The British absolute unit is that force which, acting on one pound of matter for one second, generates a velocity of one foot per second. In some definitions the grain is used as the unit of mass instead of the pound: it is manifestly inconvenient to use the grain; the pound is the unit now generally accepted. The French unit of mass is the gramme, of time the second, as in England, and of space the metre. In the absolute unit, mass and space are regarded once, but time twice; for time of action is considered, and likewise velocity, which depends on time and space. The absolute or kinetic unit force described above is employed in scientific investigations, and on this unit the absolute units employed in electric and magnetic measurements are founded; if the force of gravity acting on one pound of matter were employed as the unit force in these cases, it would be inconvenient by reason of the necessity for in every case defining the place on the earth's surface at which gravity was supposed to act. The force of gravity at the poles is to that at the equator as 1 to 1·005133; it does not vary in the British Isles for one degree difference in latitude more than $\frac{1}{12000}$ of its whole amount in any place. Engineers adopt in practice the force of gravity acting on a national standard of mass as the unit of force, rather than the absolute unit: the variation of the force of gravity with difference of place being confined within such narrow limits, it may be neglected in practice without giving rise to inconvenience; hence, British engineers use the British standard pound weight, and French engineers the kilogramme, as the unit of force, using the absolute unit only for theoretical investigations, where strict accuracy is essential.

3. Although not used in practice, it is essential the absolute unit, and the relation between it and the gravity unit, should be understood. The force of gravity acting on a given mass may be expressed in absolute units, by dividing the mass of the body into the velocity it would acquire in falling *in vacuo* by its own weight for one second. A pound of matter allowed to fall in Great Britain would acquire in one second a velocity of 32·2 feet per second; the action of gravity on one pound of matter is

therefore equal to 32·2 absolute units; or, the British absolute unit of force is about half an ounce, and the pressure of one pound used as a unit by engineers is equal to 32·2 absolute units. The force of gravity acting on a unit mass at the equator is 32·088, and in any latitude θ it is equal to $32{\cdot}088(1 + {\cdot}00513 \sin^2 \theta)$; 32·2 is the mean value for the British Isles. It should be remarked that weights are primarily measures of mass, their application to the measurement of force is secondary. Excepting when otherwise stated, the unit of force referred to in the following pages is the force of gravity acting on one pound of matter in Great Britain, and is equal to about 32·2 absolute units.

4. As forces involve only direction and magnitude, they are represented on paper by lines representing their lines of action; the length of each line represents the magnitude of the force according to an arbitrary scale, one end of the line represents the point of application, and an arrowhead on the line the direction. In algebraical formulæ the positive or negative sign is prefixed to quantities representing forces accordingly as the force acts in a direction arbitrarily chosen, or in the opposite direction.

5. If a body be acted upon by several forces at the same time, a single force which would produce the same result on the balance of the body as these forces is termed their resultant; in other words, the resultant is a force equal and opposite to that force which would exactly balance the given forces; the given forces are themselves termed components of their resultant. The resultant of a set of balanced forces is nothing. The resultant of any number of forces acting in the same straight line on a body is their algebraical sum; and if the forces are in equilibrio, the sum of those acting in one direction is equal to the sum of those acting in the opposite direction. The science of statics may be deduced from either one of two fundamental principles, termed the parallelogram of forces, and the theory of couples, respectively; each of these principles is a necessary consequence of the other, the former being the simpler in a large class of cases is more generally employed.

6. The smallest number of inclined forces which can be in equilibrio is three; these must act on one point and in one plane, and their relation must be such, that each one of them must be equal and opposite to the resultant of the other two. The necessary relation between two forces and their resultant, and between three forces in equilibrio, are given in the theorem of the parallelogram of forces, which may be thus enunciated:—If two forces acting on one point, both either to or from the point, be represented in magnitude and direction by

the adjacent sides of a parallelogram; then, the diagonal of the parallelogram drawn through the point will represent in magnitude and direction either their resultant or a third force which would balance the other two, according as it acts to or from the point with the other two, or in a contrary direction. Thus, if AB, AC (fig. 1) represent two forces in magnitude and direction acting on a point A, the parallelogram ABCD being drawn, the diagonal DA will represent in magnitude and direction their resultant; and, if the arrowhead at D were reversed, as shewn at A, the diagonal would represent in magnitude and direction a force which would balance the forces AB and AC.

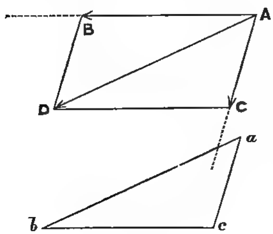


Fig. 1.

7. Lines related to each other in magnitude and direction, as the sides and diagonal of a parallelogram, evidently bear to each other the same relation as the three sides of a triangle; therefore the principle of the equilibrium of three forces acting in the same plane on a given point, is sometimes termed the triangle of forces; it is enunciated as follows:—If three forces be represented in direction and magnitude by the three sides of a triangle respectively, then those forces acting in the same plane through one point are in equilibrio; and conversely, if three forces acting in the same plane through one point balance each other, they may be represented by the sides of a triangle in magnitude and direction. Thus the three forces acting on the point A, fig. 1, are represented in magnitude and direction by the sides of the triangle *abc*. It follows from the above, that for three forces to balance each other any two must be greater than the third; that each must be proportional to the sine of the angle between the other two; that they must act in one plane; and, generally, the conditions ruling the relative magnitudes of the sides and angles of triangles apply to the representation of three forces in equilibrio; and unless these conditions are fulfilled in such representation the forces cannot balance each other. The relations between the lines representing the forces being such, problems concerning the forces may be solved trigonometrically as well as graphically; thus, two forces and the angle between them being given, their resultant, or a third force which would balance the other two, may be found; or, three forces being given, the angles between them when they are in equilibrio may be found, &c.

8. The resultant of three or more forces acting on a point may be obtained by the parallelogram of forces by finding, firstly, the resultant of any two of the forces, and then using this with a third one of the forces as components to obtain a second resultant, and so on until the last resultant, which will be the resultant of all the given forces; a force equal and opposite to this resultant would balance the forces. This is stated in the following corollary from the parallelogram of forces termed the polygon of forces. If a number of forces acting through the same point be represented by lines equal and parallel to the sides of a closed polygon, those forces balance each other; for, if the parallelogram of forces be applied to find their resultant, as described above, it is evident, if the forces are balanced, this resultant will be nothing; or, dividing the polygon into triangles by lines drawn from one of its angles, it follows from the triangle of forces: that AC, AB, BC, fig. 2, balance each other, AD, AC, and CD are balanced, and AD, DE, EA are balanced; therefore the system of forces is in equilibrio. In other words, CA is the resultant of CB, AB; DA the resultant of DE, AE; and DC, CA, AD are in equilibrio. It is not necessary that the closed polygon be plane, its sides may be in different planes, in which case it is said to be *gauche*.

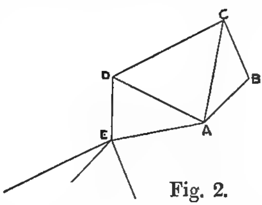


Fig. 2.

9. If three forces whose lines of action are not in the same plane act upon a point, and be represented in magnitude and direction by three adjacent sides of a parallelopiped meeting at the point A, fig. 3, the resultant of the forces will be represented in magnitude and direction by the diagonal of the parallelopiped drawn between the given point and the opposite solid angle. In the figure it will be seen that ACFE is a gauche polygon, and (the direction of AE being reversed) presents a case of the polygon of forces; for AC, CF, FE are equal and parallel to the given forces respectively; and because EA completes the polygon it is equal to the resultant of the others. Or the parallelogram of forces may be applied to such forces, as already explained (Paragraph 8), with the same result.

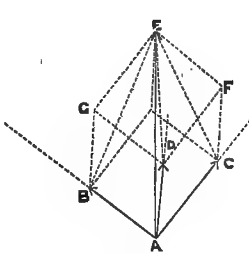


Fig. 3.

10. By means of the relations given above of lines representing forces, a single force may be replaced by two or more forces, bearing to the given force the relation of components to resultant; the given force is then said to be resolved into its resolved parts or components. For a force to be resolved into two components, it is necessary that the lines of action chosen for the resolved parts be in the one plane with the line of action of the given force, and that the three lines intersect each other in one point. From the parallelogram of forces it is evident that the two forces required must be together greater than the given force, and they must be related to the given force in magnitude and direction as the two sides of a triangle to the third side; therefore, if two components be given in magnitude, their direction may be found; if they be given in direction only, their magnitudes may be found; or if the direction and magnitude of one be given, the direction and magnitude of the other may be found, by applying the parallelogram of forces, either by completing the parallelogram graphically, or by solving the problem trigonometrically. Thus, in fig. 1, if it be required to resolve AD into two resolved parts acting in the lines AC, AB on the point A; if the parallelogram be completed by drawing the lines DC, DB parallel to the given directions AB, AC, then AB, AC will be the resolved parts required.

11. The resultant of any number of forces acting on a point, and having their lines of action in the same plane, may be found thus:—Choose two axes passing through the given point A, fig. 4, in the common plane of the lines of the forces, and making any angle with each other; resolve each of the forces into two components, one in each of the chosen axes; the resultant of all the forces in each axis is the algebraic sum of the components in that axis. If this sum in both axes is 0, or there is no resultant, then the forces balance each other. If there is a resultant in each axis, then these resultants being treated as components, a final resultant may be found by the parallelogram of forces. The axes are usually taken at right angles to each other, in which case they are termed *rectangular axes.*

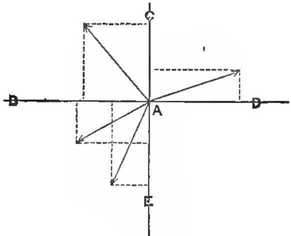


Fig. 4.

12. A force may be resolved into three components acting in given lines inclined to each other, if the given lines intersect the

line of action of the force in one point; in this case three planes are drawn from E, fig. 3, parallel to the planes of AD, AC, AD, AB, and AB, AC, respectively; the components required are represented by the portions of the given lines between the point A and the point of their intersection of the three planes respectively—viz., by AD, AB, AC.

13. When a force is resolved into components whose lines of action are at right angles to each other, the components are termed rectangular components; thus, in Paragraph 11, if the axes chosen be at right angles to each other, each of the forces is resolved into two rectangular components. The component of a force in any direction is termed the effective component in that direction, and it is evidently obtained by resolving the force into two rectangular components—*i.e.*, the effective component of a force in any direction is the product of the force, and the cosine of the angle between its direction and the direction of the required component. A force is resolved into three rectangular components by drawing three lines perpendicular to each other, AB, AC, AD, fig. 3, and from E letting fall perpendiculars to each of these lines, EC, ED, EB; AB, AD, AC are the rectangular components required. The resultant, the perpendiculars from E, and the components, form three right-angled triangles, and in each case the $\frac{\text{component}}{\text{resultant}}$ = cosine of the angle between the resultant and component. As each component is equal to the product of the resultant into the cosine of the angle between them, the square of each component will equal the square of the resultant multiplied by the square of the cosine; C_1, C_2, C_3 being the components, A_1, A_2, A_3, the angles between them and the resultant, and R being the resultant, adding the squares :—

$$\text{(A.)} \quad C_1^2 + C_2^2 + C_3^2 = R^2 \cdot (\cos A_1^2 + \cos A_2^2 + \cos A_3^2);$$

but the quantity in brackets is equal to unity; therefore

$$\text{(B.)} \qquad C_1^2 + C_2^2 + C_3^2 = R^2, \text{ and}$$

$$\text{(C.)} \qquad R = \sqrt{C_1^2 + C_2^2 + C_3^2}.$$

Thus, to decompose a force into three rectangular components, each component is equal to the product of the resultant into the cosine of the angle between it and the component required. The intensity of the resultant is given in equation (C), and its direction by the following :—

$$\text{(D.)} \qquad \cos A_1 = \frac{C_1}{R}, \cos A_2 = \frac{C_2}{R}, \cos A_3 = \frac{C_3}{R};$$

As the resultant lies in the solid angle, the angles A_1, A_2, A_3 are

acute, and as the sum of their cosines is equal to unity, if therefore two be given, the third is the defect of their sum from unity.

14. If any number of forces act on a point in lines not in the same plane, the resultant of such a system of forces is found by resolving each force into components acting in three rectangular axes, as in Paragraph 13; the algebraic sums in these axes are then treated as components, and a resultant found, as in Paragraph 13. This resultant is that of all the given forces. If the resultant be 0, then the forces are in equilibrio, and, when any number of forces are in equilibrio, their projections upon any plane or upon any line will also be in equilibrio.

15. The above principles may be applied to forces acting on a perfectly rigid body, thus:—If two or more inclined forces be applied to the same point in a rigid body destitute of weight, then the conditions of equilibrium are the same as those already stated for a point. If the forces be applied to different points in such a body, the assumption of absolute rigidity supposes that force applied to any point in that body is transmitted without loss to any other point of the body lying in the line of action of the force; and therefore the action of the force on the body will not be altered if its point of application be transferred from any point in the body to any other point, provided the second point lies in the line of action of the force. Thus, in fig. 5, ABC being a rigid body, the points of application of the two forces being transferred from A and C to 1, and the resultant 1, 2, being found by the parallelogram of forces, this resultant may be transferred to 3, 4, or any point in the body in the line 1 4; the line 3 4 represents the resultant of the forces AC; and, with its algebraic sign changed, the force which would balance them.

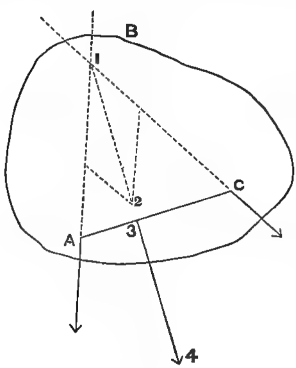


Fig. 5.

16. If from any point in the line of action of the resultant (fig. 5) two lines be drawn perpendicular to the lines of action of each of the components respectively, the ratio between the perpendiculars is the inverse ratio between the components to which they are perpendicular respectively; and either component may be replaced by any force acting in a new direction without disturbing equilibrium, if the perpendicular distance of

the line of action of such force from any point in the line of action of the resultant, multiplied by the substituted force, be equal to the product of the perpendicular distance of the line of the other component, and the force of that component. Each of the components in the above case acting alone, would tend to turn the body in the plane of its action; the efficiency of a force to turn a body about a given point is directly as the perpendicular distance of the line of action of the force from the given point, and as the magnitude of the force; or, as the product of the perpendicular distance into the force. This product is called the moment of the force—*e.g.*, a force of x pounds acting at a perpendicular distance of y feet from a given point has a moment with respect to that point, and with respect to an axis passing through that point and perpendicular to the plane of the force of xy. The moment of a weight resting on a bracket, fig. 16, with respect to the point of support, is the product of the distance of the weight from the support and the weight; with a weight w of 10 lbs. 5 feet from the support, the moment $= 50$, which represents the efficiency of the weight to bend the bracket at A. The moment of a physical agency is the numerical measure of its importance; thus, in the above example, the moment of a weight of 10 lbs. placed 5 feet from the support of the bracket AB $= 50$ foot-pounds; if the bracket were lengthened to 10 feet, and the weight reduced to 5 lbs., the moment would still be 50—*i.e.*, the efficiency of the weight to break the beam would be the same in each case. The moment of a force with respect to a given axis or point, measures the efficiency of the force to produce rotation about that axis or point. The moment of a force about a point is the product of the force into the perpendicular to its line of action from the given point, and is therefore equal to twice the area of the triangle whose vertex is the given point, and whose base is a line representing the force in magnitude and direction. The moment of a force relative to a straight line perpendicular to the line of action of the force, is the product of the force and the shortest distance between it and the given straight line; if the force be parallel to the straight line, its moment is zero; if the line of action of the force be oblique to the given straight line, the force being resolved into two components, respectively parallel and perpendicular to the straight line, the moment of the force with respect to the given straight line is the product of the perpendicular component, into the shortest distance between the given line and the direction of that component—*i.e.*, it is the moment of the perpendicular component with respect to the *point*, at which a plane drawn through this component, perpendicular to the straight line, meets that line. The moment of a force with respect to a plane is the product of the force, and

the perpendicular distance of its point of application, from that plane. The moments of forces are said to be expressed in foot-pounds, inch-pounds, &c., according to the units of length and weight employed.

17. Unbalanced forces in the same line, or inclined to each other, acting on a single point or a rigid body, impress on it a motion of translation; but forces may impress or tend to impress a motion of rotation, and this effect remains to be considered. Two forces of equal magnitude acting on the same body in parallel and opposite directions, but not in the same line, constitute a couple. The arm or leverage of a couple, AB, fig. 6, is the perpendicular distance between the lines of action of the two equal forces A and B. The plane of a couple is the plane in which are situated the lines of action of the two forces. The tendency of a couple is to turn the body to which it is applied in the plane of the couple. A couple is termed right-handed when it tends to rotate the body in the same direction as the hands of a watch, fig. 6; left-handed when the tendency is to rotate the body in the opposite direction. The moment of a couple is the sum of the moments of the forces about any point in their plane, and therefore is equal to the product of the arm of the couple and one of the equal forces; it measures the tendency of the forces to rotate the body. If the length of the arm be given in feet, and the forces in pounds, the product is termed the moment in foot-pounds, as explained for moments of force (Paragraph 16); the term *foot-pound* is also used in another sense, and therefore, in using the term as above, the term "moment" should be prefixed to prevent confusion. The moment of a couple may be represented by the area of a rectangle, whose adjacent sides are lines representing the arm and one of the equal forces respectively; or, by a single line drawn perpendicular to the plane of the couple, and of a length proportionate to its moment; this line is sometimes termed the axis of the couple, but properly the axis is any line perpendicular to the plane of the couple. Algebraically, right-handed couples are usually considered positive, left-handed negative; lines in an axis are usually considered positive when drawn in the direction from which the couple must be viewed to appear right-handed.

Fig. 6.

18. 1. Two couples are equivalent when their moments are equal, they act in the same direction, and in the same or parallel planes. This is the fundamental principle of the theory of couples; from this principle it follows:

2. The resultant of any number of couples acting in the same plane, or in parallel planes, is equivalent to a couple, the

moment of which is the algebraical sum of the moments of the component couples.

3. Two or more couples in the same or parallel planes balance each other when the resultant moment—*i.e.*, the algebraical sum of their moments—is nothing.

4. If the two adjacent sides of a parallelogram represent the moments of two couples whose planes are inclined to each other, the diagonal of the parallelogram will represent the moment of the resultant couple equivalent to the two couples compounded, both in magnitude and direction—*i.e.*, three couples whose moments represented by lines form a triangle, balance each other.

5. If any number of couples acting on a body be represented by the sides of a closed polygon, they are in equilibrio.

6. Couples represented by lines may be compounded or resolved into components as single forces; in applying the methods given already under the parallelogram of forces, it is necessary to remember that the components and resultants so obtained are, in the case of couples themselves couples, represented by lines in the axis, of a length proportionate to the magnitude of the couples represented respectively.

19. A balanced system of parallel forces must consist either of pairs of equal and directly opposed forces, of equal couples, or of combinations of such pairs and couples; for no single force can be found which will balance a couple. The magnitude of the resultant of any system of parallel forces is the algebraical sum of their magnitudes, and if this resultant is nothing the system is in equilibrio. The relative positions of the lines of action of parallel balanced forces is solved by means of the theory of couples; in the consideration of such cases all pairs of directly opposed equal forces are neglected. If three parallel forces applied to a body are in equilibrio, the following conditions are fulfilled: their lines of action are in one plane, the extreme forces act in the same direction as each other, and in the opposite direction to the centre force, and the magnitude of each force is proportional to the distance between the lines of action of the other two. If, in fig. 7, the three forces be considered as two pairs of forces forming two couples, whose arms are AB and BC respectively, and whose moments are equal, it will be seen that

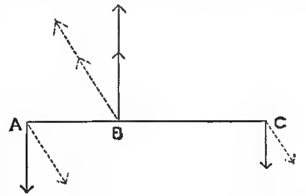


Fig. 7.

for the system to be in equilibrio the conditions stated above

must be fulfilled—*i.e.*, the middle force must equal the sum of the extreme forces, as the moments of the couples must be equal the lengths of the arms must be inversely as the forces respectively, and it is evident the forces may be inclined without disturbing equilibrium if they maintain their parallelism to each other. This principle is that of the lever; the three forces represented in the figure may represent the pressures of power, fulcrum, and weight, and the lever will be of the first, second, or third kind, according to the order in which these are arranged. As in the case of inclined forces, if three parallel forces are in equilibrio each must be equal and opposite to the resultant of the other two.

20. The resultant of a couple and a single force acting on a body in the same or a parallel plane is found as follows:—Set off from 0, fig. 8, the point of application of the given force F, a line – F equal and opposite to F; through 0 draw the arm of a couple and complete the couple by the force F, the moment of this couple being made equal to that of the given couple by increasing or decreasing the length of the arm in the inverse ratio of the force F to each of the forces of the given couple; it is evident the resultant of this system is the force FA; for F and – F, being equal and opposite, neutralise each other, therefore the resultant is equal in magnitude to the given single force, its direction is parallel to that of the given force and in the same plane, but its point of application is shifted to the left or right accordingly as the given couple is right or left handed. Hence the resultant of any number of parallel forces must be either a single force or a single couple; for if it were a force and a couple, these could be combined into a single force.

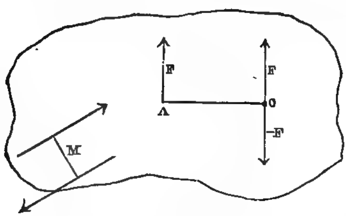


Fig. 8.

21. The conditions of equilibrium of a system of parallel forces having their lines of action in one plane are as follows:—1*stly*. The algebraical sum of the forces must be $=0$; and, 2*ndly*, the algebraical sum of their moments relative to an axis at right angles to the common plane of their lines of action must be $=0$. This is equivalent to stating that there must be neither motion of translation nor of rotation.

If the given forces be not in one plane, then for them to be in equilibrio the second condition given above must be replaced by the following:—

The sum of their moments relative to *two axes* at right angles to each other, and to the lines of action of the given force, must be $=0$.

22. 1. The resultant of any number of parallel forces whose lines of action are in one plane, equals the algebraical sum of the several forces; and the distance of the line of action of this resultant from an assumed axis, to which the forces are referred, is found by dividing the sum of the forces by the sum of their moments relative to this axis.

2. The resultant of any system of parallel forces not in the same plane is found by taking two rectangular axes; the resultant in this case, as in the last, is the algebraical sum of the several component forces; the distance of the resultant relative to each axis is the quotient of the algebraical sum of the moments relative to that axis, by the magnitude of the resultant. If in the two cases given above the resultant be = 0, then the forces are either in equilibrio or their resultant is a couple. If the forces *are not* in equilibrio, then in 1, the moment of the resultant couple is the sum of the moments of the given forces relative to the axis chosen; in 2, two resultant couples are obtained, one about each of the chosen axes; the moments of these couples are the sums of the forces relative to each of the axes respectively, and their axes will be one on each of the chosen axes; if on each of these axes a line is set off in the positive direction representing the couple (Paragraph 17), and the rectangle of which these lines are adjacent sides be completed, the diagonal will represent the resultant couple in moment and direction.

The value of the moment of this ultimate resultant will be the square root of the sum of the squares of the two component couples; and generally the same formulæ as were applied to single inclined forces may be applied to these couples, by using lines to represent couples in accordance with the rules already stated. Thus, the two component couples and their resultant couple are related to each other as the sides of a triangle, both in magnitude and direction; the cosine of the angle made by the resultant couple and either of the component couples is equal to the quotient of the component taken by the resultant; the value of either component is the product of the cosine of the angle between it and the resultant and the resultant. The resultant may be found by taking the square root of the sum of the squares of the components, because, the axes being rectangular, the components and resultant are related as the sides of a right-angled triangle, in which the resultant is the hypothenuse; or the resultant may be found by taking the quotient of one of the components by the cosine of the angle between that component and the resultant.

23. The resultant of any number of forces and couples may be found by applying the methods already given for parallel and inclined forces and couples respectively; thus, the forces and

couples being represented by lines in the conventional manner, if acting in one plane, two, and if acting in different planes, three rectangular axes are taken; to these axes co-ordinates are drawn, so that the single forces be resolved into resultants acting in the rectangular axes, and the couples are also resolved into couples acting round the same axes; the several resultants thus obtained are compounded into a single force and a single couple respectively. If the moment of the couple and the resultant of the force each = 0, the system is in equilibrio; if the moment of the couple only = 0, the resultant force is the resultant of the system; when the resultant force only is = 0, then the resultant is a couple. If the resultants of a system of couples and single forces be a couple and a single force, three cases are possible: 1*stly*. Let the single force be at right angles to the axis of the couple; this case is one of parallel forces, for the couple may be turned until its forces are parallel to the single force, and a resultant of the couple and single force may be found (Paragraph 20), for it will be equal and parallel to the single force in a plane perpendicular to the axis of the couple, and at a distance from the point of intersection of the line of action of the single force and the axis of the couple equal to the quotient of the moment of the couple by the single force. 2*ndly*. If the single force act in a line parallel to the axis of the couple, then they cannot be compounded into either a single force or a couple; the simplest equivalent of the system has been attained. 3*rdly*. If the axis of the couple and the line of action of the single force be oblique to each other, then the couple may be resolved into two component couples, one having its axis at right angles to the line of action of the single force, and the other having its axis parallel to that line; the first of these couples may be compounded with the single force (Paragraph 20), but the single force so found cannot be compounded with the second couple: the two together form therefore the final resultant of the system of forces and couples. The moment of the couple is the product of the moment of the original resultant couple, and the cosine of the angle between it and the original resultant force.

24. Forces have been considered above as undistributed, but every force must be distributed over some surface or through some volume. The *intensity* of a force is the ratio between the force in units of weight and the area or volume over or throughout which it is distributed—*e. g.*, a force of 10 lbs. distributed over 5 square feet of surface would have an intensity of 2 lbs. per square foot, a force of 9 lbs. distributed through a volume of 3 cubic feet would have an intensity of 3 lbs. per cubic foot. The only force distributed through volume which is considered in

engineering is gravity; in this case it is assumed that every particle of a body is equally attracted by the earth, the greater weight of one body compared with another being due, not to greater force acting on each particle, but to a greater number of particles acted upon. Instances of forces distributed over surface are furnished by every case in which a solid is subjected to force—*e. g.*, in a wire subjected to tension the tensile force is distributed over the cross-sectional area of the wire, and is resisted by an equal and opposite force exerted by the wire, and also distributed over the sectional area at any conceivable cross section. For a distributed force may always be found either a resultant force, a resultant couple, or a combination of a single force and a couple, which is its equivalent in action on the equilibrium of the body.

25. Gravity is the force with which bodies tend to move towards the earth. It is exerted between each body and the earth, and between any given body and others surrounding it; but the greater relative size of the earth renders it possible generally to neglect, without sensible error, the gravity between contiguous bodies, and regard that force only which is exerted between the chosen body and the earth. Each particle of matter is affected equally by gravity; the different weights of equal masses of different kinds of matter is assumed to be due to a variation in the number of particles in equal volumes. The relative greatness of the earth's radius renders it possible to assume that the lines of action of the force of gravity between the particles of the body and the centre of the earth are parallel. The force of gravity hence presents an example of parallel forces, the resultant of which must be equal to their sum, and act in their common direction. In the case presented by gravity the parallel forces are equal in magnitude, and all in the same direction; hence, the resultant cannot be a couple, it must be a single force acting in the common direction. The position of the resultant relative to any axis being given by the quotient of the sum of the moments relative to that axis, by the sum of the forces; in this instance the forces being equal, this is simply the mean distance of the forces, or that line about which the particles of the body are most symmetrically arranged. Two rectangular axes being taken the line of action of the resultant is found; if three axes be taken a point is found through which the resultant passes in every position of the body with respect to the earth, this point is the centre of gravity of the body; it is the central point around which the matter of the body is distributed most uniformly. For a body to be supported it is necessary evidently, that the gravitating forces acting on its particles be balanced by a force equal and opposite to their resultant; thus, if a body be

suspended or supported, the line of action of the resultant must pass through the point of suspension or support. The characteristics of the centre of gravity are as follows :--1. If the centre of gravity be supported, the resultant of all the forces of gravity acting on the particles will be opposed in every position of the body, and the system will be in equilibrio; and every body supported by a single force must have its centre of gravity in the line of action of that force. 2. The algebraical sum of the products of each particle of the body into its distance from a given plane, is equal to the product of the whole mass into the distance of its centre of gravity from the same plane. The centre of gravity may be defined as the centre of the parallel forces for the weight of the body.

26. Assuming a body to be equally heavy for the same bulk throughout its mass, then the centre of gravity of a geometrical figure is the position of the centre of gravity, assuming the figure to be filled with matter. If a body have a centre of figure, that point is also the centre of gravity; if it have an axis of symmetry, the centre of gravity is in that axis; and if it have a plane of symmetry, the centre of gravity is in that plane; as already stated, it is the centre of the body's mass. The common centre of gravity of a set or system of bodies is the centre of parallel forces for the resultants of their several weights. The centre of gravity of any triangle is in a line from the point of bisection of one side to the opposite angle, one-third of the length of this line from the side taken, or, it is the point of intersection of lines bisecting two sides at right angles. The centre of gravity of a cone or pyramid is on the axis at quarter the height of the figure from the base. In a conic frustrum the centre of gravity is given by the expression $L \cdot \frac{3R^2 + Rr + r^2}{R^2 + Rr + r^2}$, in which L = length or axis, R and r radii of greater and smaller end respectively. In a paraboloid it is two-thirds the axis from the vertex; in a frustrum of a paraboloid it is $\frac{1}{3} L \cdot \frac{2R^2 + r^2}{R^2 + r}$ from centre of the lesser end. In a hemisphere it is three-eighths of the radius from the centre. Irregular figures may be divided into triangles.

27. The centre of gravity has been called the centre of position, the centre of mean distance, that point which, being supported, the body is supported, &c.; it is, as explained above, commonly defined as the point always traversed by the resultant of the system of parallel forces for the weight of the body or system of bodies. If the action of gravity be reducible to a single force in a line passing always through one point, fixed relatively to the

body, whatever be its position relatively to the earth, that point is the centre of gravity of the body; but it has been pointed out by Messrs. Thomson and Tait, that, except in a definite class of cases (the bodies being therefore termed *centrobaric*), there is no one fixed point which can be termed a centre of gravity; in common parlance the term "centre of gravity" has an extended signification, being used as equivalent to "centre of inertia" (Paragraph 32); and although the fundamental ideas involved in the two terms are essentially different, in ordinary cases a proximate solution is available, according to which the extended meaning may be applied.

28. *Gravity* is, as already explained, the tendency to transmit into every particle of matter a certain velocity, absolutely independent of the number of particles; *weight* is the effort which must be exercised to prevent a given mass from obeying the law of gravity (Condorcet). The intensity of the weight of a body may be expressed in two ways, absolutely by the number of units of weight in a unit of volume, and relatively by the ratio it bears to the intensity of the weight of a standard substance. For the first the term *heaviness* has been suggested (Rankine); the second is termed the *specific gravity* of the given body. The heaviness of substances is stated by British engineers in pounds per cubic foot of volume; and specific gravity is the ratio between the weights of equal volumes of the given body and pure water at a temperature of 62° F. and an atmospheric pressure of 14·7 lbs. per square inch. The weight of a cubic foot of pure water at the standard pressure and temperature is 62·355 lbs.; hence, the heaviness of any substance in pounds per cubic foot may be obtained by multiplying its specific gravity by 62·355. In France the unit of weight is the *kilogramme*, being the weight of a cubic décimètre of pure water at its maximum density (temp. 39°·1 F.); as water at its maximum density is used as a standard instead of water at 62° F. as in England, the weight of any substance in kilogrammes is its specific gravity, and the heaviness and specific gravity are indicated by one number; but water at 39°·1 F. weighs 62·425 lbs. per cubic foot, instead of 62·355 lbs., its weight at 62° F.; thus numbers representing specific gravities on the French system, referring to a heavier standard, are for each substance slightly less than those referred to the British standard. The heaviness and the specific gravity of materials used in construction are important data, and are stated for each material in describing its properties.

29. The cases of distributed forces other than gravity most common in practice are those in which the force is either uniformly distributed over the surface, and of one kind; or uniformly

varying, and either of one kind, or of two kinds, the resultant of the two kinds forming a resultant couple. Instances of uniformly distributed forces are furnished by the tension on a wire, and the pressure on a column, the force being equally distributed over the section of the wire or column. In this case the point of action of the resultant force, or the centre of force, is at the centre of gravity of the section; it is equal to the whole force on the section, and its intensity is equal to the total force divided by the area of the section—*e. g.*, 100 lbs. distributed over 10 square inches would be said to have an intensity of 10 lbs. per square inch. The resultant is evidently equal to the force per unit of area multiplied by the area of the section. When the force is not equally distributed over the section, it may generally be assumed to vary uniformly directly as the distance of the point chosen from a given line; in this case the resultant will equal the mean intensity, multiplied by the area of the surface over which it is distributed: the point of application of the resultant will be the point where the force has its mean intensity. When the force distributed over a given area is of two kinds, as tension at one place and pressure at another, the resultant is found separately for each kind of force, and the two resultants thus found are compounded into one resultant force or a resultant couple. If the resultant forces are unequal, and of opposite signs, the resultant is their difference; the point of action of the final resultant is found by joining the points of action of the provisional resultants, and taking the point in this line distant from each force respectively, inversely as the magnitude of the force (Paragraph 19); if the forces be equal and opposite, then they have not a single resultant, they form a couple which is the resultant couple of the system. An instance of this is described in another place as presented by a loaded beam.

SECTION II.—*Force considered Dynamically—Inertia—Work.*

30. Except in defining the absolute unit of force, in the preceding section forces were considered statically; certain elementary ideas of the action of forces regarded dynamically and considered essential are the subject of this section. Dynamics applies to the conditions of *solid* bodies in motion; and as forces can only be known by their effects, the movements of solid bodies are regarded as the effects of forces, and from these effects are deduced the theoretical principles of the abstract mathematical science. Dynamics is distinguished from statics by the greater number of elements considered, the principal additional element being *time;* which, as already stated, is considered twice in the absolute unit of force (Paragraph 2).

31. Matter at rest requires force to set it in motion; if motion were impressed upon it by any force, and the force ceased to act, the motion would continue for ever at the same rate, unless some other force acted to destroy or modify it. If a force continue to act on a body after impressing on it motion, then the motion will be increased, and will continue to increase so long as the force continue to act, provided no other force opposes this motion. The mass of a body is the product of its density by its volume—*e. g.*, of two bodies of equal volume, if one had twice the density of the other, it would be said to have twice the mass. The velocity of a moving body is the distance it travels in a unit of time; the unit of distance commonly used is the foot or yard, the unit of time the second. The force necessary to impress a given velocity on a body is directly as the mass of that body—*i. e.*, the greater the mass to be moved the greater will be the force required to impress on it any given rate of motion. In other words, matter is itself assumed to be absolutely inert or passive, and all motion, cessation, and alteration of motion are ascribed to force; this inertness of matter is termed *inertia;* and the fact that the force required to impress a given velocity on a body is proportional to the mass of matter, is expressed by the statement, that inertia is proportional to mass, or quantity of matter.

32. A point the distances of which from three planes at right angles to each other are respectively equal to the mean distances of a given group of material points from these planes, is termed the centre of inertia of the given group. As a point so situated with respect to three planes at right angles to each other, must fulfil the condition for every other plane, the centre of inertia may be defined as that point the distance of which from any plane whatever is equal to the average distance of the given points from the same plane, or whose distance from any plane whatever is equal to the sum of the products of each mass, into its distance from the same plane, divided by the sum of the masses. Applied to a material system, the points may be connected, as in a single body, or they may be detached; they may be equal or unequal in mass, but in the latter case the greater must be conceived as divided; the point may fall within or without the mass or masses considered. The moment of inertia of any material point with reference to any axis, is the product of its mass and the square of its distance from the axis; applied to a system of material points it indicates the exact energy of rotation in a rotating body. The term moment of inertia, conventionally used with reference to the section of a beam, &c., signifies the moment of inertia of the system of points forming the surface of each section, about the

neutral axis of the section: the neutral axis passes through the centre of gravity of the section (defined in Paragraph 26). The moments of inertia for several common forms of section are as follows :—

Rectangle.—$I = \frac{1}{2} \times b \times d^3$;

Triangle.—$I = \frac{1}{12} \times b \times d \times (\frac{1}{4}b^2 + \frac{1}{3}d^2)$;

Circle (solid beam).—$I = \frac{1}{4}r^4 \times 3{\cdot}14156$;

Circle (hollow beam).—$I = \frac{1}{4} \times 3{\cdot}14156 \times (r^4 - r_1{}^4)$;

For sections whose figures are similar, or are parallel projections of each other, the moments of inertia are to each other as the breadths and as the cubes of the depths of the sections.

33. Velocity is termed *uniform* when the moving body moves over equal distances in equal periods of time; *accelerated*, or *retarded*, when in successive equal periods of time the distances travelled are successively greater or less. Variable velocity for any instant is measured by the mean velocity for an infinitely small space commenced at that instant. If a force continue to act on a body after it has set the body in motion, such force will continue to impress still further motion on the body, and the motion is thus accelerated; this is the case with a body falling under the influence of gravity, in each succeeding interval of time the velocity is greater from the continued action of the force. The laws of the composition and resolution of forces described in Sect. I., apply to velocities—*i.e.*, velocities may be represented by lines representing the relative distances moved over in equal times, arrowheads being used to mark the direction of the motion; these lines may be applied as described in Sect. I. The velocities so represented may be compounded into resultant, and resolved into component velocities, &c., exactly as described for forces. Also, if for a force a velocity be substituted (Paragraph 16), the moment of a velocity about a point may be obtained, the moment of a rectilineal motion with respect to a point being the product of its length and the distance of its line from the point, as defined for a force. The velocity of a body is directly as the force which sets it in motion and inversely as its mass.

34. The measure of a force is the quantity of motion it produces in a unit of time; this quantity of motion is termed the *momentum;* in a rigid body moving without rotation it is directly as the product of the velocity and the mass moving, and the force is said to communicate to the body a momentum equal to this product: the absolute unit of force is founded upon this

principle. The moment of momentum about a point is the product of the momentum and the perpendicular distance of the line of motion from the point. The sum of the momenta of the parts of a system in any direction is equal to the momentum in the same direction of a mass equal to the sum of the masses, moving with a velocity equal to the velocity of the centre of inertia of the system—*i. e.*, the velocity of the centre of inertia in any direction is the mean of the velocities of the several points of the system in the same direction.

35. Besides the modes of estimating or considering force given above, there is one other mode—viz., by the work a force can do; thus, a body in motion is said to possess *vis viva, force vive,* living force, kinetic energy, or capacity for performing work; and this *work* must be distinguished from the *force* measured by the momentum of the moving mass. A force is said to do work if its place of application has a positive component motion in its direction; and the work done is measured by the product of the force and this component motion. The work done during an infinitely small displacement of the point of application of a force, is termed the virtual moment of the force: it is the product of the resolved part of the force in the direction of the displacement and the displacement. It follows that unless a force produces displacement of its point of application in the direction of its action it does no work; and also, when the point of application of a force moves only perpendicularly to the line of action of the force, such force does no work. Thus, no work is done against gravity when a weight is moved horizontally, nor between a pendulum cord and bob, nor by the attraction between the sun and a planet when the latter moves in a circle with the sun as centre, although in all these cases forces are in operation. If a body be raised from the earth perpendicularly, or in the direction of the earth's radius, then the whole of the force used to raise the body is used to do work; if a body be raised from the earth obliquely, or a planet do not move in a circle round the sun, but in an oblique path, by which its distance from the sun is increased, then in both cases work is done against the force of gravitation; but the force is applied obliquely, and the force actually applied to perform work is the resolved part in the direction of the force of gravity in each case respectively. For the force required to move a body obliquely from the centre of the earth against the force of gravity, is less than the weight of the body in the ratio of the perpendicular distance moved to the length of the path; thus the amount of the work done is the same whether the body be removed from the earth perpendicularly, or removed to the same distance by an oblique path,

however long. It should be remarked, that if work be done by a force acting against gravity as above, then if the body so raised be permitted to fall again by the action of gravity to its original level, it will do in falling just as much work as was performed in raising it; for in raising it the work done was measured by the force multiplied by the displacement in the line of action of gravity; and if the body be suffered to fall, then the work done in falling is measured in the same manner by the force of gravity multiplied by the displacement in the line of action of gravity; for in each case the displacement is equal, but in opposite directions, and the forces are equal, for the force which acted to raise the body must have been equal to the force of gravity to which it was opposed, and it acted in an opposite direction; hence the work done in raising the body may be said to be stored up ready to be yielded up again when the body shall be permitted to fall to its original position. Gravity is chosen in the examples given, but the elasticity or expansive force of steam, of springs, or other agencies, may be readily used to furnish similar examples; thus, a locomotive engine drawing a train on a level track does no work in opposition to the force of gravity, for the motion of the train has no positive component in the line of action of the earth's attraction; but it moves the train against the resistance of the air and the resistance of friction, and in this case the measure of the work done is not the weight of the train multiplied by the distance moved, as in the other example, but it is measured by the force actually required to overcome the retarding forces, per unit of distance multiplied by the distance travelled. When a piece of india-rubber is stretched, the force employed does work in stretching it; so long as it be kept stretched it exerts force opposite to the force which keeps it extended, but such force does no work; if the cord be permitted to contract, in contracting the force with which it contracts performs work equal in amount to the work performed in stretching it, the work in each case is measured by the product of the force exerted, and the distance moved through. A given quantity of work may be performed in a relatively long or short period of time; the element of time must therefore be included to completely determine work, for upon this element depends what may be termed the intensity of the work performed—*i.e.*, the rate at which it is done.

36. The *vis viva* or kinetic energy of a moving body is proportional to the mass of the body, and to the square of the velocity of its motion; if the momentum, force, or quantity of motion of a body be used up in doing work by raising a weight in opposition to gravity to a certain height (neglecting the

resistance of the air, and considering only gravity), as already explained, in falling from this height again, the weight raised would acquire under the action of gravity exactly its original velocity. The velocity a body must have to cause it to rise to a given height, is precisely that velocity it would acquire in falling from that height; but the height is in both cases proportional to the square of the velocity; or, in other words, its kinetic energy is proportional to the square of its velocity, as already stated. The above example illustrates the difference between force and work, and it may be seen to be true when work is done against the action of other agencies than gravity. Work is sometimes improperly described as force acting in opposition to resistance, but the idea of force involves that of resistance. The essential idea of work is displacement of the point of application of the force. A force impresses momentum on a body without acting through space; but to consider the work a force can do, it is essential to consider it as acting through space; for the work is measured by the product of the force and the displacement—*i.e.*, the space through which the force continues its action. Kinetic energy or *vis viva* is the directly proportionate result of work. If work be done on a body in the absence of other forces which can do work or have work done against them, the result is an equivalent change of kinetic energy. If work be done against such forces, the increase of kinetic energy is less than in the former case by the quantity of work required to overcome such resistance; but in this case the body is endowed with an equivalent potential energy, as in the examples given of the opposition of gravity.

37. The absolute unit of force being that force which would bestow a unit velocity on a unit mass in a unit time, and the work it would do being as the square of the velocity, which in this case is unity, the absolute unit force is that force which does a unit of work in a unit of time. Thus, if a body weighing 10 lbs. have a velocity of 5 feet per second, it would do $5^2 \times 10 = 250$ absolute units of work—*i.e.*, compared with gravity its momentum would raise 250 times half an ounce, or about 7 lbs. 13 oz., 1 foot high in 1 second; in other words, the absolute unit of work measured in gravity is the work required to raise about half an ounce weight 1 foot high in 1 second. The absolute unit is used in scientific investigations, as explained for the absolute unit force, but, as in that case, engineers use a gravity unit in preference, and for the same reasons. The unit of work employed in practice by British engineers is termed the foot-pound; it is the work requisite to raise 1 lb. weight 1 foot high in 1 second; and it is in terms of this unit that the efficiency of machines, the *vis viva* of moving bodies, &c., are

expressed—*e.g.*, the efficiency of steam engines is expressed in horse power, one horse power being equal to 33,000 units of work per minute, or the work expended in lifting 33,000 lbs. 1 foot high each minute.

38. The work done by a force or couple in turning a body about an axis is the product of the moment of either, and the value of the angle in circular measure through which the body is turned, provided the moment remains the same in all positions of the body. If the moment be variable, then the above is true only for infinitely small displacements, and the work done may in this case be ascertained by taking the average moment.

SECTION III.—*Friction.*

39. Friction is that force which acts between bodies at their surfaces of contact to resist their sliding on each other. The principal laws of this force are as follows:—It is simply proportional to the force with which the bodies are pressed together, provided the pressure be not so great, compared with the area of the surfaces in contact, as to indent or abrade either body, the pressure acting at right angles to the surfaces. It varies with the nature of the surfaces in contact. The relation between the friction and the pressure for a given pair of surfaces is termed the co-efficient of friction for that pair of surfaces—*e.g.*, the friction between two surfaces of cast iron, without any lubricant, is 0·16 of the force with which the surfaces are pressed together; hence this number is the co-efficient of friction for these surfaces under the given condition. It is independent of the velocity with which the surfaces move, if they be moving over each other, but the friction between bodies which have remained some time at rest in contact is greater than that between the same surfaces when in motion; the first is termed the friction of rest, and the second the friction of motion. Slight vibration is sufficient to change friction of rest into friction of motion, hence the co-efficient of the latter is employed in practice. It is independent of the area of the surfaces in contact.

40. Between fibrous substances, as cloth, friction is increased by surface, and diminished by pressure and velocity; it is generally greatest with soft, and least with hard substances. Between dissimilar substances the measure of friction is determined by the limit of abrasion of the softer substances.

41. When the rubbing surfaces are covered with an unguent, as oil or tallow, the friction is greatly reduced; it does not then vary with the substances rubbing, but with the nature and

quantity of the unguent between the rubbing surfaces. The unguents commonly employed are oil, oil and black lead, grease and tar, and soap. Grease is mixed with tar to prevent it being run out by heat; this mixture, sometimes termed cart grease, is used for cart wheels. Soap is a good lubricant for wooden surfaces, and is used in India for cart wheels having wooden axles, being less likely to run than fat. Hog's lard and oil are better lubricants between metal surfaces than tallow. The following are recipes for anti-friction grease:—1. Hog's lard, gutta percha, and black lead; 2. hog's lard, with 20 per cent. of black lead. Most of the grease manufactured for lubrication is unmixed with black lead, but it is made alkaline. The layer of unguent should be continuous, and to gain the maximum advantage from its use it must not have less than a certain thickness.

42. The general laws stated above apply to the friction of axles upon their bearings. With the exception of fibrous materials, friction is generally greater between the same material than between different materials, and is greater when the surfaces are very smooth than when somewhat rough; this is attributed by some authorities to the action of cohesion.

43. When a body is placed on an inclined plane it has a tendency to slide down the plane; the force which resists this tendency is the friction between the two surfaces in contact. If fig. 9 represents a body on an inclined plane, it is evident the weight of the body may be resolved into two components, respectively parallel and perpendicular to the inclined plane ABC; the parallel component represents the force with which the body tends to slide down, the perpendicular component the force with which the body is pressed against the inclined surface. The friction between the surfaces must not be less in proportion to the pressure applied than the relation between ac and cb; if it be less, the body will slide down the inclined plane. If the parallel component bears the ratio to the perpendicular component expressed by the co-efficient of friction for the particular materials of which the surfaces are in contact, the body will be on the point of sliding down, and the angle abc or ABC is termed the angle of repose (sometimes the angle of friction).

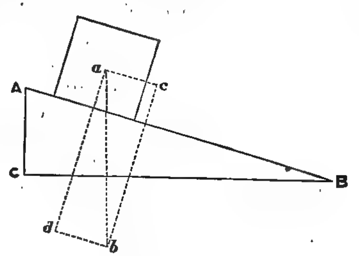


Fig. 9.

As ab and ad are perpendicular to CB and AB respectively, the angles ABC and abc are equal. When about to slide, $\frac{ac}{cb}$ equals the co-efficient of friction for the particular surfaces employed, but $\frac{ac}{cb}$ = the tangent of the angle ABC; hence the angle of repose for any two substances is that angle the tangent of which is equal to their co-efficient of friction. If this angle be exceeded in an inclined surface, the friction will be insufficient to maintain the body at rest, and it will slide. A table of co-efficients of friction and angles of repose is given in Paragraph 49.

44. The angle of repose is of great importance in forming banks of earth or sand, in building blockwork structures, &c. If a bank be made with a greater slope than the angle of repose, the earth will slip until the angle is reduced to that of repose, unless other forces than friction resist the tendency to slip. The stability due to friction between surfaces in contact is termed the stability of friction; in the case of loose earth and sand, water in small quantity somewhat increases the co-efficient of friction, but in large quantity it acts as an unguent, and tends to destroy frictional stability entirely, in which case cohesion alone resists the tendency to change of form.

45. In drawing a carriage on a horizontal road the angle of the direction of the draught (the traces) with the road, termed the angle of traction, should not evidently be greater than the angle of repose; but obliquity of draught within this limit is advantageous. The following ratios of slopes for vehicles, being the angles of repose, or the most advantageous angles of draught on horizontal roads, are given as likely to prove useful:—Wheels with iron tires—road, sand and gravel, 1 in 16; broken stone (ordinary), 1 in 25; condition perfect, 1 in 67; well made pavement, 1 in 71; oaken planks (not planed), 1 in 98; stone trackway (well laid), 1 in 179; railway, 1 in 280; iron shod sledge on hard snow, 1 in 30.

46. If a rope be twisted round a cylindrical body, as a post or tree, the friction is so considerable that, with one complete turn round a smooth cylinder, a tension of 1 unit on one end of the rope will balance about 9 units on the other end; with two turns 1 unit tension, applied at one end, will balance $9 \times 9 = 81$ units on the other end; and generally, as the number of turns is increased in arithmetical progression, the advantage due to friction increases in geometrical progression. This fact is applied in lowering heavy weights, and generally to gain control over a rope subjected to tension, when the force at command is small

compared with the tension on the rope. It explains the efficiency of a knot in a rope, in which case the rope is bent round itself, the friction being rendered still greater by the rough and yielding surfaces.

47. When a band passes round a drum, as in driving machinery by a band, the friction is dependent on the angles A, C, fig. 10, at which the cord meets the surfaces, or the angle ABC, and the co-efficient of friction only. The shape and size of the transverse section of the drum do not influence the friction; but in practice, if the band be stiff, there is probably an advantage in using drums of large radius. If the cord or band pass completely round the drum, the friction, as in the last case, is independent of the size and form of the section of the pulley or drum; it is dependent only on the co-efficient of friction for the particular materials employed. When a pulley or drum is turned by a band, the friction increases the strain on the band on one side of the pulley, and diminishes that on the other side; the sum of the tensions is constant, the tension on one side being increased by just as much as that on the other is diminished.

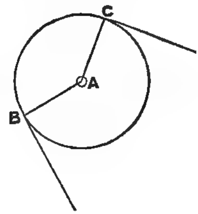


Fig. 10.

48. Friction is the agent to which is due the efficiency of the arrangements for stopping machinery, termed brakes. The most common form of brake is formed of blocks of hard wood, fixed on an iron strap or arm, passing round the whole, or a portion of the circumference of the wheel to be acted upon, and admitting of being tightened on the wheel by suitable levers or screws. The form termed "Appold's brake" is that commonly introduced into cable-laying machinery, for controlling the rate at which the cable leaves the ship during the process of paying out. The principle is as follows:—A, fig. 11, represents a wheel the motion of which is to be reduced by friction on its circumference, a strap of iron DEC passes completely round the wheel A, the ends of this strap DC are attached to a lever AB, movable about A, the end C being fixed to the lever farther from its fulcrum A, than the end D. If the end B of the lever AB be depressed, the strap is evidently tightened on the circumference of the wheel; if B be raised, the strap is loosened; for, in either case, the end

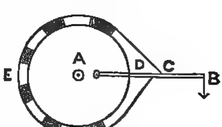


Fig. 11.

C being farther than D from the point A, it moves through a greater distance for a given movement of B. The arrangement is in a great measure automatic: if a weight be suspended to B, it will cause the strap to press against the circumference of the wheel with a force dependent on the weight at B, the length of the lever AB, the distances AD, AC, and the nature of the surfaces in contact; if from any cause the friction between the wheel and strap increases, the weight at B is lifted thereby, and the pressure diminished; if the friction decrease, the weight falls slightly, tightens the strap, and increases the friction; hence the effect of the arrangement is to act as a constant force acting to retard the motion of the wheel A on its axis. This regularity of action has led to the adoption of this form of brake for laying cables. The cable passes several times round one or more grooved drums, generally two, and the weight of the cable hanging in the sea over the stern of the vessel causes the drums to revolve and the cable to run out; to control the revolutions of the drum, and prevent the cable from running out too rapidly, an Appold's brake is applied to the edge of a wheel rigidly fixed on the same axis as the drum; the iron strap does not press directly on the drum, it is lined with blocks of hard wood, through which the pressure is communicated. Instead of a weight being attached at B, in the most perfect machinery B is connected with a piston moving in a hydraulic cylinder, and the brake is tightened or loosened by putting pressure on the upper or lower surface of the piston.

49. The co-efficients of friction of motion for a few frequently occurring cases, are as follows:—

Iron on stone, ...	·3 to ·7
Timber on timber, ...	·2 to ·5
Timber on metals, ...	·2 to ·6
Metals on metals, ...	$\frac{1}{5}$ to ·25
Earth on earth, ...	·25 to 1·0
„ „ wet clay, ...	·31
„ „ shingle and gravel, ...	·7 to 1·11
Smooth surfaces greased, ...	·05 to ·08
Smoothest and best greased surfaces, .	·03 to ·036

As already stated, the angle of repose is that angle the tangent of which is equal to the co-efficient of friction. In practice, the angle of repose is expressed as in Paragraph 36—*i.e.*, by the ratio between the vertical rise and the horizontal distance, or as the tangent in the angle of repose to 1; thus, the angle of repose for earth on earth, in common language, is a rise of 1 in 4 to 1 in 1. (*Vide* table above.)

CHAPTER II.

GENERAL PRINCIPLES OF STRENGTH OF MATERIALS.

SECTION I.—*Definitions—General notice of Strength, Elasticity, &c.*

50. THE external forces acting on a structure, or part of a structure, constitute the *load* on the structure or part. The load produces more or less alteration of volume and figure in the piece of material acted upon—this is termed *strain;* it may be expressed by the quotient obtained by dividing the alteration of some dimension of the body by the original length of that dimension. *Stress* is the force with which the piece of material resists the tendency of the load to strain and fracture it; it is the force exerted between the particles of material which resists the load, and is necessarily equal to the load. The *intensity* of stress is represented by the quotient obtained by dividing the total stress expressed in units of weight, by the extent of the surface over which it is distributed, expressed in units of area—*e. g.*, it may be expressed as so many tons or pounds on the square inch or foot of the sectional area of the material, as explained for distributed forces generally (Paragraph 24). That property of a solid of resisting forces tending to change its figure is termed *rigidity* or *stiffness;* it is expressed as a co-efficient or modulus of stiffness by the ratio of the intensity of the stress to the strain. The reciprocal of the co-efficient of rigidity is the co-efficient or modulus of *pliability.* The term "*elastic flexibility*" is applied to signify the extent to which a body may be strained without suffering fracture—*e. g.*, vulcanised india rubber is the most elastically flexible of known bodies.

51. The property of stiffness, together with that of regaining more or less completely its original form and volume on removal of the load producing strain, is termed *elasticity.* If the return to its original dimensions be complete, the solid is said to be *perfectly* elastic; if any permanent alteration in figure remain after the withdrawal of the straining force, this alteration is termed a *set,* and the body is said to be imperfectly elastic. No substance is perfectly elastic; like electrical conductivity, and many other qualities of bodies, elasticity is never absent, but is always imperfect. It is, however, sensibly perfect if the stress be restricted within narrow limits, and nearly perfect up to a certain limit, sometimes termed the limit of elasticity, or of perfect elasticity. Co-efficients and moduli of elasticity measure the stiffness only within those limits of stress wherein the

elasticity is sensibly perfect; when so limited, the strain is directly proportional to the stress. The co-efficient of elasticity is the strain produced by a unit load (1 lb.), acting on a piece of material of a unit transverse sectional area and a unit length; the modulus of elasticity is the reciprocal of the co-efficient. It will be evident, on consideration, that the modulus of elasticity of a piece of material, for its resistance to stretching or compression, represents the force per unit of transverse area required to stretch or compress it respectively through a range equal to its original length. The moduli of elasticity given in books are those for direct elasticity, or resistance to stretching and to compressing forces, which are sensibly equal for the same material within the limits of elasticity; and transverse elasticity, or resistance to distortion. The greatest number of experiments have been made on the resistance of bodies to lengthening, and this is, as a rule, referred to in tables; the co-efficient of transverse elasticity has been obtained by experiment for very few substances only. As already stated, moduli of stiffness are the relation between the intensity of the stress and the consequent strain (Paragraph 50); moduli of elasticity are simply moduli of stiffness when the stress is so limited, that the elasticity is sensibly perfect. Moduli or co-efficients of elasticity given in tables, are generally expressed as the number of pounds pressure per square inch of section, which would compress or stretch the body through a distance equal to the original length of the body itself (which, as we have seen, is equal to the reciprocal of the co-efficient of elasticity), the elasticity being assumed perfect—*e. g.*, if a stress of 50 lbs. per square inch compressed or elongated a body through one-tenth of its length within limits of perfect elasticity, then 500 lbs. per square inch would at the same ratio compress or elongate it through a length equal its own length, and 500 lbs. per square inch would be its modulus of elasticity, which, it is evident, is a purely hypothetical quantity, having no possibility of existence in reality. Caoutchouc is the only substance which can be so stretched without fracture. British engineers use the British units; French engineers express moduli of elasticity in kilogrammes pressure per square millimetre of transverse sectional area, as explained for distributed forces generally. Moduli of elasticity and strength are sometimes expressed in heights or lengths of the material itself. These heights or lengths signify the height or length of the column of the material which would weigh as much per unit of sectional area as the modulus—*e. g.*, if the modulus of elasticity were 500 lbs. per square inch, and a cubic inch of the material weighed 1 ounce, a column sixteen times 500, or 8000 inches high, and 1 square inch

cross section, would weigh 500 lbs.; a column 666·6 feet would press on its base 500 lbs. per square inch, and the height of the modulus of the material would be thus 666·6 feet. As there is no necessary connection between the elasticity or strength of a solid and its density, this mode of expressing the moduli is of very limited application in practice. Tables of moduli of elasticity used in practice refer to resistance to direct stretching; resistance to compression is more difficult to ascertain, and would be of less utility, the phenomena being more complex.

52. It was supposed that no set was produced by loads within the limit of elasticity, but it is now known that loads well within this limit do cause a set ;* and it is highly probable that every load, however small, causes a set on its first application, the set in the case of a relatively small load being inappreciable. The set due to the action of a load within the limit of elasticity, is not increased by repeated applications of the load; and, after having received such a set, the material is more perfectly elastic for loads not exceeding that which produced the set. If a load exceed the limit of elasticity of the material, repeated applications of the same load cause an increasing set, until the material is either fractured or fails by being distorted so much as to become useless. The limit of elasticity, or of perfect elasticity, the elastic strength or the proof strength, of a piece of material, is now more correctly defined as the greatest stress it will bear without injury—*i.e.*, the greatest stress which does not produce an increasing set on repeated application. Hard, vitreous, and earthy bodies, as glass, bricks, &c., are brittle; they appear elastic through the whole extent of their cohesion, they take no set, and fail without exhibiting the phenomenon of strain.

53. The load producing the proof stress is termed the proof load. For loads exceeding the proof load the strain is not proportional to the stress producing it, but increases in a much faster ratio than the stress; when the load exceeds the proof load, an addition of one-eighth of the ultimate load may double the strain. The breaking load, or ultimate strength of a body, is the force required to fracture it in some specified way, as tearing, crushing, &c. The load borne by a piece of material in practice is termed the *working load*; it is made less than the *proof load* in a certain ratio determined by experience, to allow for imperfections of workmanship, of materials, and other contingencies. The ratio in which the breaking load exceeds the working load is termed the *factor of safety*—*e.g.*, if a structure be so constructed that its ultimate load is four times the greatest load it can ever bear in practice, its factor of safety is said to be four. The safe-working load does not exceed the proof load, it lies generally considerably

within it; and in some substances but a small proportion of their strength is available by reason of their great pliability.

54. In testing materials the load is gradually increased from 0 to its maximum; when the proof or ultimate load is mentioned, it is always assumed that the load is added gradually, without vibration or impact; in this case the load is termed a dead load. If, instead of increasing from 0 to its maximum, the load be applied at once, the strain immediately on application of the load is double that the same load would cause if applied gradually. A load applied suddenly is termed a live load; and the factor of safety to resist a live load must be made double that to resist the action of a dead load. If the load be mixed, then each portion must be multiplied by its own factor of safety, that of the live portion being made double that for the dead portion; in other words, if the load or any portion of it is borne continuously, or applied gradually, the strength of material required to resist the action of such load or part need be only half that requisite to bear the same load or part of it, if suddenly applied. Structures required to bear the application of a suddenly applied load, are made twice as strong as similar structures required to bear a dead load.

55. The period during which a load is applied influences its effect on the material; a relatively small load applied for a considerable time may produce a sensible set; whereas, a much greater load applied for a short time may have no such effect A load equal to three quarters of the breaking load, and therefore considerably beyond the proof load, has been applied to an iron beam for a short time without causing appreciable set. A load does not produce its ultimate set the instant it is applied, time is necessary to admit of the set acquiring its maximum; thus, a bar of iron may be snapped suddenly, producing a scarcely appreciable set; whereas a considerable set might be produced by a smaller load suffered to act so as to break the bar slowly. This fact is of great importance in testing materials to be afterwards employed in construction; but, as a rule, materials to be employed must not be tested beyond their proof strength. If a load exceed the proof load by a small amount only, the piece of material may not fail until after a considerable lapse of time, or thousands of different applications of the load; hence weakness of a structure may not appear until long after the structure has been in use—the mere fact that it fulfils its purpose at first is alone no proof that it will continue to do so without accident. This explains why structures sometimes fail after having apparently afforded proof of sufficient strength, by resisting successfully for a long period the load under which they ulti-

mately fail; and why telegraph spans break occasionally without apparent cause.

56. If a load be applied with impact and vibration, a smaller load will suffice to produce fracture than if the load be applied without shock or vibration. Vibration is most destructive when the vibratory motion is caused to accumulate by the application of shocks at regular intervals of time; a suspension bridge and a tight span of telegraph wire are caused to vibrate by gales of wind, which for this reason may prove destructive to such structures if not provided against. Such being the effect of vibration and shocks, it is evident stiffness is an important element in estimating strength. For this reason it is frequently necessary either to use more material than mere strength apart from stiffness requires, or to dispose material in other than the strongest manner, in order to gain sufficient stiffness. It is evident, also, if a piece of material be too stiff, it may be fractured by reason of its want of power to absorb the force of a shock by its elasticity.

57. The energy or quantity of mechanical work of the greatest shock a piece of material will bear without injury—*i.e.*, of the shock which will produce the proof strain—is termed its resilience or spring. If E be the modulus of elasticity, $\frac{1}{E}$ will be the co-efficient of elasticity. Let l represent the proof load per unit of section, then the total elongation under this load will be $\frac{l}{E}$, and for a bar originally of the length x, $\frac{lx}{E}$, and this represents the distance through which the force of the load acts in stretching the bar to its proof strain. If s be the area of cross section of the bar, the load being applied gradually will vary between 0 and ls, and its mean will be $\frac{ls}{2}$; the work done in stretching the bar to the proof strain will be—

$$\frac{ls}{2} \cdot \frac{lx}{E} = \frac{l^2}{E} \cdot \frac{sx}{2};$$

i.e., the resilience of the bar is obtained by multiplying half its mass by the quotient obtained by dividing the proof tenacity by the modulus of elasticity. The factor $\frac{l^2}{E}$ is termed the modulus of resilience; and it is evident a suddenly applied load $= \frac{ls}{2}$, or

half the proof load, produces double the strain it would produce if gradually increased from 0 to its maximum (Paragraph 54). If therefore half or nearly half the proof load be suddenly applied, it will produce the proof strain. In producing this strain the load will move through the distance the material is strained through, acting in opposition to the stress of the material; the work done by such load in straining the material is therefore the load multiplied by the distance it moves through in producing the proof strain. This work, measuring the energy requisite to produce the proof strain, is the resilience or spring of the particular piece of material. In other words, the resilience is equal to the proof strain, multiplied by the mean load, which acts to produce that strain. The resilience of materials is of great importance in estimating the strength of structures liable to shocks. The quantity of work in the greatest shock to which the material is liable in use, and its resilience, should in such cases be compared, and provision made to ensure that the elasticity of the material be not impaired by the shocks which it is required to successfully resist. In practice resilience is considered with reference to tension; it might be considered with reference to compression, but from the complexity of the phenomenon of crushing it would be of little practical utility.

58. Conditions are frequently imposed by the nature of a material which prevent such material being employed to the greatest theoretical advantage—*e. g.*, metals may be fashioned into hollow forms, whereas in wood such forms are obviously inadmissible. This is one of the reasons why the metals have superseded wood for so many purposes, although iron is so much heavier specifically than wood; ships' masts and spars, for instance, may be made stronger, and yet lighter, of iron than wood. Conditions are also frequently imposed by the mode in which materials are worked, which prevent the strongest form being imparted to a given mass—*i. e.*, render it necessary to use more of the material than strength requires; *e. g.*, in casting metals, great and sudden inequalities of thickness have to be carefully avoided, because the thin metal would cool so much quicker than the thick, that the casting would either be fractured in cooling, or so weakened as to be rendered unsafe. It is evident a knowledge of the operations by which materials are worked is necessary to the engineer.

59. The existence of slight defects, the greater difficulty of working, and of obtaining large masses of uniform good quality throughout, cause large pieces of material to be weaker relatively than small pieces of the same material; hence, where admissible, it is more economical and safer to use small rather than large

masses. The strength of a model of small size is proportionately much greater, therefore, than a similar structure of working size; therefore the strength of a projected structure cannot be directly deduced from the strength of such a model.

60. The effect of increase of temperature is generally to reduce the elasticity of solids, causing them to become softer and weaker.

61. When a piece of material is loaded in such a manner that the weight of the material itself acts in the same direction as the external load, then this weight must be considered part of the load, and added to the external load to obtain the gross load. In estimating the strength of a given solid, the gross load must always be considered. If the weight of the material form part of the gross load, the strength in similar bodies does not increase in proportion to the increased weight of the material if the dimensions of the body be increased. In such case, the larger the piece of material the greater the proportion of its strength used up in supporting its own weight, and the smaller the external load it will bear safely compared with its dimensions, until, with a certain dimension, it will only bear its own weight. This is termed the limiting dimension; thus the limiting length of a beam, or the limiting height of a column, is that length or height of the particular material at which the material itself would be equal to the ultimate load of the beam or column respectively, or the beam or column would support no external load. The limiting span of a wire is that span which, with the least possible tension, the wire would be at the point of rupture. It is manifest, in the examples given, that the transverse dimensions do not affect in any way the limiting lengths; the latter are invariable for the same material, and depend on the relation between the heaviness and strength of the particular material. Hence there is a limit to size in construction imposed by the ratio between the strength of the material and its heaviness.

62. It is usual to consider the external load only as a preliminary in designing structures, and by the term load this is generally referred to. If the weight of the piece of material is small compared with its load, this weight may be neglected; in all other cases it must be considered and provided for; in no case should it be entirely overlooked. The method stated above, which is that of false position, is of great use in simplifying the work of designing, and is very generally used by engineers. It is manifestly much easier to fix the dimensions of materials provisionally, then examine and modify them until the correct dimensions are arrived at, than to endeavour to calculate directly the necessary dimensions from complex data.

63. In examining surfaces of fracture to ascertain the mole-

cular structure of a piece of material, it is necessary to consider the degree of suddenness with which the force acted which produced the fracture; if this acted gradually, the fractured surface of a fibrous body will shew the fibrous structure; but if the force acted very suddenly, the fibrous appearance may not be developed, and the material may be wrongly judged to be granular in structure.

64. Moduli of strength are expressions for the ultimate stress per unit of sectional area of the layer which first begins to yield, the force being applied in a given manner; they are sometimes expressed in length of the material itself. There are as many moduli of elasticity, resilience, and strength for each material, as there are modes of applying force to strain it. The moduli have generally different values for the same material, according to the manner of application of the straining force—*e.g.*, the strength of a material to resist tension bears no necessary relation to its power to resist compression. Cast iron, for instance, offers six times the resistance to crushing it offers to tearing, while in wrought iron the tenacity exceeds the resistance to crushing. Not only do materials differ from each other in strength, and the strength of each material differ according to the mode of action of the straining force, but most materials have for the same kind of stress a different modulus of strength, according to the mode of application of the force considered in relation to the internal structure of the material—*e. g.*, the tenacity of fibrous substances, as wood, is generally greater in the direction of the fibres than at right angles to this direction.

65. A load may be applied longitudinally in two ways, producing either *compression* or *extension;* with the breaking load the material is in the former case crushed, and in the latter torn asunder. A load may be applied transversely in three ways as follows:—The piece of material may be bent and ultimately broken across; the strain in this case is sometimes termed *transverse strain,* more generally bending strain, and an instance is afforded by a bar of timber or metal supported at the ends and loaded in the middle. The piece of material may be *twisted* until it is wrenched asunder; shafts transmitting power are subjected to twisting force; the breaking of a steamer's screw shaft in heavy weather is an instance of breaking by twisting. The third mode in which the force may be applied is to produce distortion, and ultimately fracture the piece of material by *shearing* or *detrusion.* In this case the line of fracture is in the same direction as the force, one piece being pushed along on the other; bolts and rivets are subjected to shearing stress. If two plates riveted together be made to slide on each other (if the plates do

not fail), the rivets are first distorted, and ultimately sheared through. In short, a piece of material may be strained and ultimately fractured, by pressure, tension, breaking across, wrenching or torsion, and shearing or detrusion. A piece of material forming part of a structure may be subjected to one kind of strain, as in the case of bolts and rivets, which suffer shearing stress; or it may be strained in several ways at the same time, as in the case of a piece of timber joined to other timbers by bolts, in which the timber resists the direct action of a load, and the tendency of the bolts to shear out a layer of wood from the bolt holes.

66. Materials are most economically applied when that kind of strength which they have in greatest perfection is brought into play—*e. g.*, cast iron being greatly inferior in tenacity, and superior in resisting pressure, to wrought iron, the former is more frequently employed to resist pressure and the latter to resist tension; while brickwork, having a very low degree of tenacity, is not subjected to tension as a general rule.

67. But few kinds of material are homogeneous when in large masses, and different specimens of the same material differ between very wide limits in strength and elasticity. Although numerical constants are given, they must not be supposed applicable to every specimen of the same material; in the case of so variable a substance as timber, for example, probably such constants as those of deflection, Paragraph 143, would not agree exactly in any two specimens; while there is an infinite number of different qualities of material between cast and wrought iron of extreme qualities. Such constants are average results of experiments, the extreme results obtained differing frequently very widely; thus such constants cannot be considered as applicable to any particular specimen. The moduli given in tables generally refer to average quality without faults. The conditions affecting the strength of particular specimens must be considered, and experiments made when necessary, to ascertain if the specimens to be used are equal to average quality; and care should always be taken in selection. In applying rules and tabular numbers to the calculation of the strength of materials, it is evident such rules and numbers cannot be blindly used with safety; observation and judgment are necessary, and the result has frequently to be confirmed or supported by experiment. In applying numerical co-efficients and moduli in practice, the two principal points to be attended to are—1*stly*, that the material to be employed is of the proper quality; and 2*ndly*, that the case presented is (as far as possible) exactly similar to that from which the co-efficient was deduced by experiment.

SECTION II.—*Resistance to Pressure.*

68. For stresses less than the proof stress, the resistance to longitudinal compression is sensibly equal to the resistance to stretching; for such stresses the strain is directly proportional to the load producing it. The resistance to compression, the load being limited, does not bear a fixed relation to the resistance to crushing; a material which offers a higher resistance than another to crushing, may, under a limited load, offer a less resistance to compression.

69. The phenomena presented on fracture by compression are regulated by the length of the piece broken, as compared with its transverse dimensions, and by the molecular structure of the material. If the length of the body greatly exceed its diameter, the effect of longitudinal pressure is to bend and ultimately break it across; in this case the failure is by breaking across transversely, and the resistance to direct crushing is not tested. The tendency to break by cross breaking commences when the length exceeds about 5 diameters in cast iron, 10 diameters in wrought iron, and 20 diameters in dry wood; but if the proportion of length to diameter be less than that of 3 to 2, the friction of the surfaces between which the body is crushed affects the result by holding the parts together, and making the strength appear greater than it really is.

70. The principal laws of resistance to direct crushing offered by short pieces of uniform section are as follows:—

The resistance is directly as the area acted upon, the load being uniformly distributed—*e.g.*, a prism of uniform section of 2 inches sectional area, would require twice the force to crush it required by a similar prism of the same material of 1 inch, or half the sectional area. If the load be not uniformly distributed, the crushing load is reduced in the ratio the mean stress is less than the maximum stress—*e.g.*, if the mean stress be half the maximum stress, then the crushing load will be half that of the same body for a uniformly distributed load.

71. The crushing load is influenced by the form of section. Of four prisms of equal sectional area the cylindrical was the strongest; then in order of strength the square, the rectangular 4×1, and the equilateral triangular; the difference between the strongest and weakest was about 14 per cent. A pillar of uniform transverse dimensions is stronger than one of the same content which tapers—*e.g.*, a cylinder is stronger than a truncated cone, and more so as the inequality of the diameters of the latter is greater. Of rectangular pillars of the same content and

length, the square section is the strongest. If a prism or column be built up of several pieces, as in brickwork and masonry, the resistance offered to crushing is inferior to that of a similar prism formed of a single block; and the structure is weaker the thinner the courses. The strength of the structure is increased if the blocks be cemented together. If the strength of the cement exceed that of the pieces cemented, and it be strongly adhesive, the strength of the structure may even exceed that of a single block.

72. The phenomena of crushing differ with the nature of the material crushed. Hard homogeneous substances, as vitreous bodies, split in a direction almost parallel to the direction of the load, the surfaces of fracture being smooth. Granular substances, as brick and cast iron, offer greater ultimate resistance to pressure than to tension, and fail by sliding or shearing. The surfaces of fracture are oblique to the direction of the load, the degree of obliquity varying with the nature of the material (with cast iron it varies from 42° to 32°, according to quality). The fracture may take place at a single plane surface, or the block may be broken into pyramidal or wedge-shaped pieces, or both mixed, preserving the angle between the surfaces of fracture and the direction of the load proper to the material. Most granular materials, as brick and stone, begin to splinter and crack when under less than their ultimate load—*e.g.*, brick begins to splinter at from one-half to two-thirds its ultimate load. Only the hardest materials, as very hard stones and cast iron, fail suddenly. Ductile and tough materials yield gradually by bulging until they are pressed flat; their tenacity is generally greater than their resistance to direct crushing. The gradual manner in which such materials yield to pressure renders it exceedingly difficult to determine exactly their ultimate resistance to direct crushing. Fibrous materials, as timber, are crushed by buckling or crippling; the pressure being directed along the fibres, they become wrinkled and separate from each other. The resistance to crushing of such materials is generally much less than their tenacity.

73. Tables of the strength of materials to resist a crushing force have been compiled from the results of numerous experiments made by different persons; the tabular numbers generally represent the ultimate resistance to crushing in pounds pressure on the square inch of transverse section, the specimen being too short to fail by bending, and free to expand laterally. If the lateral expansion be interfered with the resistance to crushing is increased; it is evident with perfect lateral support the material could not be fractured by direct crushing. The modulus of

resistance to crushing is sometimes expressed in height of a column of the particular material; this height is that of an isolated column, in which crushing of the base would just commence by reason of the weight of the superincumbent mass. In other words, the shortest column which would not support its own weight—*e.g.*, the modulus of cast iron is about 58,000 feet—*i.e.*, a column of that height would not stand, as the lowest part would be crushed by the weight of that above.

74. Those bars or rods in a structure which resist pressure applied to them longitudinally, are termed *struts* with respect to such pressure; they are necessarily practically inflexible. A column is a vertical strut. The strength of a column or strut of given material to resist longitudinal pressure, depends on the length of the strut compared with its diameter, on the form of its transverse section, on the mode of fixture of its ends, and on the direction of the pressure with reference to its axis. The limits of length below which a column fails by crushing have been already stated (Paragraph 69); when the length exceeds 30 diameters the column fails by bending and breaking across.

75. The following laws apply to long struts—*i.e.*, those in which the length is at least 30 diameters if fixed, or 15 diameters if hinged at the ends. These columns fail in the centre, but if the diameter at the centre be made longer, their strength may be increased about one-seventh to one-eighth, and fracture in this case no longer occurs at the centre. But if hollow, the increase of diameter must not be at the expense of the thickness of the shell; in this case the strength is not increased by expanding the centre. With ends firmly fixed, a column is three times as strong as with the ends rounded or hinged. The strength of a post with one end rounded, the other fixed, is an arithmetical mean between that of a column with both ends fixed, and another with both ends rounded or hinged. Hence the importance of securely fixing columns, and expanding them at the ends. A pillar of uniform section, fixed at both ends, is as strong as a similar pillar hinged at both ends, but of half the length. Pillars hinged at one end and fixed at the other break at a point about one-third of their length from the hinged end. If a flat-ended pillar be pressed obliquely to its axis, its strength is only that of a similar pillar rounded or hinged at the ends; hence the great importance of placing pillars truly in the line of action of the load, of staying heavily loaded struts, of fixing topmasts securely in the caps by padding, &c.

76. The strength of cast-iron solid cylindrical pillars varies directly as the 3·6th power of the diameter (d) in inches, and inversely as the 1·7th power of the length (l) in feet, multiplied

by a constant (c) = 14·9 tons with rounded ends, and = 44·16 tons with flat ends; or the formula—

$$s = c \times \frac{d^{3.6}}{l^{1.7}}, \qquad (1.)$$

For hollow pillars the formula is almost the same; it becomes—

$$s = c_1 \times \frac{D^{3.6} - d^{3.6}}{l^{1.7}}; \qquad (2.)$$

The difference between the 3·6th powers of the internal and external diameters is taken, the constant c_1 is 13 tons for rounded, and 44·3 tons for flat-ended pillars.

77. The following approximate formulæ are deduced from Mr. Hodgkinson's experiments by Mr. Lewis Gordon:—

p = strength of pillar in pounds;
s = sectional area in square inches;
l = length, and
d = least external diameter,

both in the same unit of measure. For columns with both ends fixed and of any material—

$$P = \frac{fs}{1 + a\dfrac{l^2}{d^2}}, \qquad (3.)$$

and with both ends rounded or jointed;

$$P = \frac{fs}{1 + 4a\dfrac{l^2}{d^2}}; \qquad (4.)$$

f represents the resistance of the material to crushing, and is— 1. For wrought iron, rectangular section, 36,000 lbs.; 2. cast iron, hollow cylinder, 80,000 lbs.; 3. timber, rectangular section, 7,200 lbs.; and 4. for stone and brick, rectangular pillars, it is variable according to quality; the crushing strength should be selected from the tables of resistances to crushing. In the four cases given, a is $\frac{1}{3000}$, $\frac{1}{800}$, $\frac{1}{250}$, and $\frac{1}{600}$ respectively. The formulæ given above apply to the forms very generally given to the different materials named.

78. The strongest form for metal struts containing a given quantity of matter is the hollow cylinder; or for long thin struts, a rod expanded at the centre into a parabolic spindle. Cast-iron columns are generally made in the hollow cylindrical form; long

wrought-iron and steel poles for sheer legs and crane jibs are generally made spindle-shaped. The strength of cast-iron struts of the cross or hollow square form of section may be computed by means of comparison with the hollow cylinder; thus, the strength of a cross-shaped strut compared with a cylindrical one of the same diameter and sectional area, is obtained by multiplying a (formulæ 3 and 4, Paragraph 77) in the formula for a hollow cylinder by 3; the strength of a hollow square diagonal equal to diameter of cylinder, and of equal sectional area, is obtained by multiplying a by $\frac{3}{2}$. The thickness of cast-iron hollow struts is not generally less than one-twelfth the diameter, and it is necessary, whatever the material employed, that the thickness bear a certain relation to the diameter of the tube to obtain the maximum strength with a given quantity of material. Wrought iron is most economically employed in the tubular form, and may have any form of section, as rectangular, triangular, circular, &c.; the last named is the best when practicable. In calculating the strength of such forms by the formulæ given, d is the least dimension of the rectangle circumscribed about the cross section.

79. Mr. Hodgkinson's formula for the ultimate strength of posts of oak and red pine is—

$$P = A \frac{d^2}{l^2} S; \text{ or for square section, } A \frac{d^4}{l^2},$$

A being 3,000,000 lbs. per square inch, and d the least diameter. The resistance to direct crushing should also be calculated, and the smaller of the two quantities should be taken as the ultimate strength of the pillar.

80. In the case of short columns, the strength more nearly approximates to the resistance to crushing; for that portion of the strength which is used up in resisting flexure becomes less as the column is shorter, and a greater proportion of the resistance offered by the material to crushing is available to support the load. Mr. Hodgkinson's formula for long pillars of cast iron requires modification to render it applicable to short pillars:—Let b be the strength of the pillar calculated by formula 1 or 2, and c the resistance to direct crushing = 49 tons × area in square inches; then the ultimate strength of the short pillar

$$S' = \frac{4bc}{4b + 3c} \quad \text{......(5.)}$$

81. The strength of square wrought-iron cells, tested as short columns, the thickness of plate being not less than one-thirtieth of the diameter, was found to be 27,000 lbs. per square inch sectional area of iron. When several such cells joined together

were tested the strength was increased to from 33,000 to 36,000 lbs. per square inch. These results apply to cells of circular transverse section, but not to those rectangular in section when the sides of the rectangle are very unequal. Small tubes are proportionately stronger than larger of the same thickness of material.

82. There exists difference of opinion as to the length as compared with diameter at which breaking by cross-bending commences; on the authority of Rankine, 20 diameters has been stated (Paragraph 69), as this length for dry wood, Sganzin states it at 8 diameters, and Rondelet at 10. According to Rondelet the strength of wooden pillars, in terms of the resistance to crushing offered by a cube of the material, is as follows :—

Length in terms of least diameter.	Strength as compared with that of a cube of the material.
12	$\cdot 83\dot{3}$
24	·500
36	$\cdot 33\dot{3}$
48	$\cdot 16\dot{6}$
60	$\cdot 08\dot{3}$
72	·042

Such statements must be regarded as approximate only, differing probably with the kind of wood; the resistance of a cube gives a high figure for the resistance to crushing. The following table is calculated from Mr. Hodgkinson's experiments on pillars of Dantzig oak and red deal of square section :—

Material.	Length in diameters.	Strength, R. to crushing for equal cross sectional area being unity.
D.O.	17	·553
D.O.	27·4	·381
R.D.	29	·478
R.D.	29	·440
D.O.	34·5	·407
D.O.	37	·453
D.O.	46	·227

In the above table it appears there is a want of agreement, and a difference between the oak and deal, which might have been anticipated. The column 17 diameters long did not fail perceptibly by bending, but to all appearances was crushed: the relative length so far influenced the strength, that only about half the resistance to crushing was available to support the load; a similar column 17·3 diameters long failed by both crushing and

bending. The statements of Sganzin, Rondelet, and Rankine may be probably reconciled as follows :—When the length is less than 8 or 10 diameters, the whole resistance of the material to crushing is available to support the load ; but when this relative length is exceeded, the resistance is less than the resistance to crushing, although up to about 20 diameters there may be no bending perceptible. Rondelet's proportions furnish a useful rule for rough calculations. A long pillar may be regarded as a beam subjected to bending load : it bends and fails in the centre, unless the centre be made stronger than the ends. The form of a parabolic spindle given to shear poles is that form most economical in a beam supported at both ends, and loaded in the centre.

83. The pressure per square inch required to indent wood one-twentieth of an inch transversely is given below from experiments made by Hatfield (quoted by Anderson) :—

	Lbs. per Square Inch.	Sp. Gravity.
White Pine, ...	600	·388
Mahogany, Bay-wood, . .	1,300	·439
„ St. Domingo, .	4,300	·837
Oak, ...	1,900	·612
Ash, ...	2,300	·517

The above is important in considering the pressure on fastenings, clamps, saddles, &c.

84. The relative strength of pillars of different materials, deduced from experiments on long pillars with rounded ends (excepting in the case of red deal), is as follows :—

Cast Steel, ...	2,518·0
„ Iron, ...	1,000·0
Wrought Iron, ...	1,745·0
Oak (Dantzig), ...	108·8
Deal, Red, ...	78·5

85. Telegraph poles and masts fail almost invariably under excessive transverse strain; considered as pillars they have a strength greatly in excess of requirements, and there is no necessity therefore, excepting in very exceptional cases, to attend to the distribution of the vertical component of their load. The vertical load on a pole is only the weight of the wire between the lowest points of the spans on both sides of the post; or, in the case of a terminal post, between the post and the lowest point of the span ; it is the same for an angle post as for an intermediate post, and therefore but a small fraction of the ultimate load of the post considered as a strut. In the case of high masts, great care should be taken to fix the mast firmly and truly vertical (Paragraph 75).

SECTION III.—*Resistance to Tension.*

86. The phenomena of fracture by direct tension are simpler than those of fracture by crushing. A tough rod subjected to tension first stretches throughout its whole length; when the proof load is exceeded, the elongation is much greater in proportion to the load than for loads below the proof load; the elongation of an iron bar may be doubled by the addition of one-eighth of the ultimate load, after the proof load has been exceeded. Short iron bars may stretch more proportionally than long ones: a bar 120 inches long stretched, with 32 tons per square inch, 26 inches; a similar bar 10 inches long, with the same load, stretched 4·2 inches; the elongation per unit of length was thus in the two cases as 1 to 2. Mr. Kirkaldy found this was not the case with every description of iron; in some kinds the elongation was the same for long and short specimens. When fracture is about to occur, the stretching is not uniform throughout the length of the bar; the part where rupture is about to take place is drawn out and contracted transversely, and the bar fails at its weakest section. Sometimes the bar is drawn out suddenly at two places, and in exceptional cases even at three.

87. Brittle substances fail suddenly without presenting the phenomena of stretching exhibited by tough materials. The absence of indication when fracture is imminent is a source of insecurity when such substances are subjected to tension; this, together with the fact that brittle, as compared with tough substances, are deficient in tenacity, causes the employment of the former to be avoided in favour of the latter, when tension has to be resisted.

88. The pieces of a metal bar broken by tension cannot be broken by a load less than that which broke the original bar. This has received two explanations: one is, the bar has been rendered stronger by being stretched, it being an ascertained fact that wire-drawing does increase the tenacity of the metal in the direction drawn; the other explanation is, the bar failed at its weakest section, and the unavoidable relative weakness of one part has saved the other parts from deterioration. Mr. Lloyd's experiments on four successive breakages of the same bar gave—

1st breakage, ...	23·94 tons
2nd ,, ...	25·86 ,,
3rd ,, ...	27·06 ,,
4th ,, ...	29·20 ,,

The iron was good ductile quality: it stretched one-sixth in length.

and was considerably reduced laterally. From the above it does not appear that the ultimate tenacity is reduced by the material being loaded with a load less than the ultimate load. Mr. Kirkaldy has observed that screw bolts are not necessarily injured although loaded nearly to breaking point.

89. The strength of fibrous substances is greater along the fibres than perpendicular or oblique to their direction; the numerical values given in tables are, unless otherwise stated, for tension along the fibres. This difference is very marked in the case of timber; but in metals in which the fibrous structure is due to rolling, the difference of strength is very small, excepting in thin masses as plates. Rolled metal gives earlier notice of impending fracture, and contracts more transversely under an ultimate load, in the direction in which rolled, than at right angles or oblique to that direction. In some cases there is a difference of strength in iron plates, according to the direction in which strained. M. Navier found a difference of about 10 per cent.; the strength was 40·8 tons along the direction rolled, and only 36·4 tons across the fibre. Sir W. Fairbairn found the strength in the two directions almost the same, and he explains this by the different mode of piling the bars to make the plate. Mr. Kirkaldy found puddled steel and iron plates stronger, and the contraction at the point of fracture greater, when the plates were strained along, than when strained across, the fibres; but the reverse was the case with plates of cast steel, thus confirming Sir W. Fairbairn's observation. Wrought iron made by the Bessemer process, in the cast unhammered state had a mean strength of 18·412 tons; a flat ingot of the same iron rolled into boiler plate had a tensile strength of 30·50 tons, the strength was increased by rolling in the ratio of 18 to 32. The tenacity of metals is increased by wire-drawing; small-sized *hard* wires are therefore proportionately stronger than large; hence a stranded wire is safer than a single wire of the same weight per unit of length and same degree of hardness, and strand wire is preferred for town lines and long spans for this reason. Stretching metal under a tensile strain, wire-drawing, and cold rolling *diminish* the specific gravity of the metal, increasing the tenacity, and rendering it more uniform. Binding a wire with a tight ligature determines its point of rupture; the wire invariably breaks at the ligature, and is weakened by the binding.

90. The ultimate resistance to breaking by direct and uniform tension offered by a bar or rod is (as in the case of resistance to pressure) directly as the area of its transverse section; but the tension must be applied accurately along the axis of the specimen, or the ultimate load will be considerably reduced. Mr.

Tredgold calculated if the line of tension were removed from the axis to half the radius of the section, only one quarter of the strength would be available; but Mr. Hodgkinson's experiments on similar bars of the same quality iron gave 7·5 tons along the axis, and 2·62 tons along the side, or rather more than one-third. The necessity for distributing the load so that its resultant may act along the axis of the bar is evident. When material is tested for its ultimate strength, the area of the fractured bar on which the intensity of the ultimate stress is calculated, is usually the original transverse area of the bar, sometimes this area reduced by the equal stretching throughout its entire length, and not the area of the section where the extreme and local contraction has occurred, which immediately precedes fracture; but, in such substances as iron, the local contraction is an element the consideration of which is essential to a just conclusion concerning the mechanical value of the material tested. The elongation, under any load not exceeding the proof load, is evidently the intensity of the stress divided by the modulus of direct elasticity.

91. In experiments on iron rods, the square section proved proportionately stronger than the round by 1·4 per cent. Mr. Kirkaldy, in testing iron and steel, discovered that the lateral dimensions formed an important element in comparing either the rate of or the ultimate elongation; and he found the ultimate strength materially affected by the shape of the specimen; the strength was found much less when the diameter of the specimen was uniform for some inches, than when uniform for only a much shorter length.

92. Those bars or rods in a structure which suffer longitudinal tension are termed *ties.* The efficiency of a tie is not impaired by flexibility.

93. The modulus of tenacity is frequently expressed in length of the material, as in the case of resistance to pressure—*e. g.*, if the ultimate tenacity of iron wire be 80,000 lbs. per square inch, and 12 cubic inches weigh $3{\cdot}\dot{3}$ lbs., the length of the modulus of rupture is 24,000 feet or 4·5 miles—*i. e.*, a wire of this length, of any thickness, if hung perpendicularly, would be about to break at its point of suspension by reason of its own weight alone. The modulus of tenacity is calculated on the assumption that the wire or rod is suspended in vacuo; if it be suspended in any medium, the modulus in such medium will be greater than the modulus in vacuo, in a proportion dependent on the relation between the specific gravities of the material and the medium. If the specific gravity of the material be equal to or less than that of the medium, the modulus of the material in the medium will be infinite; or more correctly, the material has no finite modulus in

such medium. If the specific gravity of the material be greater than that of the medium, then the material suspended in such medium has a finite modulus, and such modulus is to the modulus of the material in vacuo in the ratio of the weight of a given volume of the material weighed in vacuo, to the weight of the same volume weighed in the given medium. This will be evident when it is considered that the weight of the material forms the load—*e. g.*, if iron weighed in vacuo have a specific gravity of 7·7, then in water it would lose $\frac{10}{77}$ of its weight, the modulus in water would be to that in vacuo as 7·7 to 6·7; or it would be greater in water than in vacuo by $\frac{10}{67}$ of its length in vacuo. Practically the density of the air is neglected, it being so much less than that of the materials, and almost invariably present; but when, as in the case of telegraph cables, the surrounding medium is water, it is necessary to consider the greater length of the modulus due to the superior density of the medium. In the case of a telegraph cable the term *modulus* is applied to the modulus of tenacity *in water;* as the cable is intended to be worked in water its modulus in air is not required. The terms *practical* and *working* modulus refer to the ultimate modulus divided by the proper factor of safety. The working modulus of a cable for use under water is the ultimate modulus in water, divided by a suitable factor of safety. The length of the modulus of tenacity expressed in the substance itself, is useful to the telegraph engineer in affording a mode of representing and expressing relations between strength and load in long spans and cables to be laid in deep water.

94. The effects of temperature on the tensile strength of iron are not completely ascertained; there is a general opinion that at low temperatures iron is more brittle or weaker than at higher temperatures, but this opinion is not founded on accurate investigation. Mr. Kirkaldy found wrought iron of superior quality had its strength reduced 3 or 4 per cent. by the lowering of its temperature below 32° F., the load being applied suddenly; but when the load was applied gradually the difference disappeared. The tensile strength of plates has been found uniform between 0° and 400° F. The best bar iron has been found to increase in strength up to 320° F., after which it diminished; but no diminution of practical importance occurs up to a much higher temperature. The tensile strength of materials is not affected to an extent of practical importance within the natural extremes of temperature experienced in temperate and tropical climates.

95. Chains and other bodies of iron subjected to violent shocks and vibration become altered in structure; they lose in time

their fibrous structure and become crystalline, weaker, and they ultimately fail. Sir W. Fairbairn thought the time requisite to produce fracture depends entirely on the intensity of the applied forces, the retardation or acceleration bearing some ratio to this intensity; the justice of this supposition is evident on consideration of the action of a load exceeding the proof load. The effect of annealing on iron the structure of which has been altered by shocks and vibration, is in a great measure to restore the original properties; hence crane chains and similar bodies are periodically annealed to render them safe, while the screw shafts of steamers and similar bodies are often changed after having been in use a certain period, to avoid accident. The general effect of annealing is to reduce the ultimate tensile strength of iron, but to render it tougher, more ductile, and consequently safer under shocks. Brittle iron has a higher ultimate tenacity than softer metal, but the softer is obviously preferable for telegraph purposes, and for engineering purposes generally.

96. Materials are commonly subjected to tension under the form of ropes and chains; if a rope be doubled round a pulley the doubled rope has twice the strength of the same rope used singly; but if the rope be passed over a rod or bar, as when a sling is passed over a crane hook, the strength of the doubled rope is less than twice that of the single rope. The same phenomenon is observed in chains: a chain having the links studded to prevent their collapse under strain has only about two-thirds to seven-ninths the strength of an iron rod equal in section to both sides of the link taken together. The effect of the stud is to distribute the strain more uniformly over the section of the link (Paragraphs 70, 90, 100). In flat link chains Sir Charles Fox found that no additional strength was gained by increasing the size of the chain link at the eye without adding to the thickness of the eye; and his experiments on links and bolts proved the following rule must be observed to attain the maximum strength with a given quantity of material:—The area of the semi-cylindrical bearing surface of the hole in the link, must be a little more than equal to the transverse sectional area of the smallest part of the body of the link; consequently, the bolts in such chains have to be made larger than the mere strength of the link would seem to indicate. The explanation of the phenomenon described is in the fact that a certain extent of bearing surface is necessary to prevent the stress being so intense as to injure one or both of the bodies in contact by pressure before the full tensile strength of the combination is reached. In the case of rope slings and ordinary chains this loss of tensile strength is unavoidable, and must be allowed for; but in chains with flat eyes and bolts, the

proper proportions may be attained, and unless they are there is waste.

97. The quantity of work required to break a bar 1 inch square in section, and 1 foot long by tensile strain, is termed Mallet's or Poncelet's co-efficient. It differs from the resilience of the bar, as already defined in considering the ultimate load instead of the proof load, and is equal to half the ultimate load multiplied by the ultimate elongation. It represents, as in the case of the resilience, the power of the material to bear shocks; but as in practice the proof load cannot be safely exceeded, the resilience appears more useful in practice.

SECTION IV.—*Resistance to Shearing.*

98. Shearing and punching are not cutting, but detrusive action, one part of the body being pushed off the other part. Unlike cutting, the separation of the parts of a body sheared through takes place suddenly, as soon as the elasticity of the body sheared and that of the shearing body have been overcome. In cutting the separation is gradual, but in shearing the material gives way through its entire thickness at once, and the recovery from the strain takes place with a jerk.

99. The resistance to shearing is somewhat less than the tensile strength of a piece of material of equal sectional area.

100. In experiments on iron bars it was found—inclined shears required less force to drive than parallel shears; flat bars required the same force to shear them with parallel shears, whether they were sheared flat or on edge; but with inclined shears and bars on edge 8 per cent., and on flat 26 per cent. of the force necessary with parallel shears was saved. The maximum resistance to shearing is offered when the stress is uniformly distributed over the section, and it is only with this condition fulfilled that the strength is directly as the sectional area. In the case of riveting metal plates together, the rivets are made to fill the holes prepared for them by the hammering they are subjected to to form the head; but when bolts or other fastenings are used to connect the links of chains, or under any circumstances which require the bolt to be loose, or which render it possible it may wear loose, the stress is no longer equally distributed over the whole transverse area of the bolt; the maximum stress exceeds the mean stress in a proportion dependent on the form of section. This proportion is, for a rectangle $\frac{3}{2}$, and for an ellipse and circle $\frac{4}{3}$. The sectional area should therefore be increased accordingly (Paragraph 96).

101. As will be shewn hereafter, shearing stress occurs in beams, but it requires to be provided against more generally in fastenings, as rivets, bolts, pins, screws, joggles, &c., which connect pieces subjected to tension, pressure, &c. When the resistance to shearing offered by the material connected is low compared with that offered by the fastenings, there is a tendency rather to shear out a piece of the material than to shear through the fastenings; this case is presented when iron wedges, pins, &c., are used with wood, or hard wood joggles, wedges, &c., are used with soft wood.

102. Punching is the same action as shearing, but is applied in a different manner. The resistance to punching has been found by experiment on iron plates slightly higher than the resistance to shearing, but less than the tenacity of a bar of transverse sectional area equal to the detruded surface of the metal punched. The laws stated above for shearing apply to punching: an inclined punch requires less force to drive than a flat one; small punches driven by hand are, however, made flat, but the operation is not in this case strictly punching throughout. In timber the resistance to shearing is greater across than with the fibres.

SECTION V.—*Resistance to Torsion.*

103. Torsion or twisting is the strain to which shafts and the axles of wheels and pinions are subjected; it is of much more general occurrence in machinery and millwork than in structures within the province of the civil engineer. A knowledge of the principal laws regulating the resistance of materials to this kind of stress is however essential, as it is liable to be produced accidentally; in some cases it is unavoidably present, and it is sometimes produced intentionally. The following are instances of torsion:—The tension of a wire acting at the end of a long bracket tends to twist the supporting post, and if the insulator by which the wire is attached to the bracket stand above the bracket, there is a tendency to twist the bracket. A mast is twisted when a yard is close-hauled, particularly when this is done with a jerk; hemp, wire, &c., are twisted in the making of joints and ropes; rope fastenings are tightened, sometimes improperly, by means of a lever inserted in a loop of the rope to twist the rope on itself. Although generally referred to shafting, the laws are of course equally applicable to any other case in which there is a twisting load acting under similar conditions. Torsion produces ultimately fracture by a kind of shearing.

104. The twisting moment of a load is the moment of the pair of equal and opposite couples, applied at different points in the length of a bar, tending to twist the portion of the bar lying between these points, fig. 12. It is evident the arc of torsion is directly as the arm of the couples AB, the distance between them CD, and the load. With the ultimate load the rod is wrenched asunder.

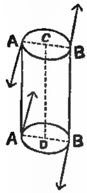


Fig. 12.

105. If a bar be twisted, the material suffers more strain the greater its distance from the axis of the bar, and the strain is not therefore equally distributed over the section; but in whatever layer the mean strain may lie, the ratio of the distance of such layer from the axis to the diameter or radius of the section will be constant for the same form of section. In a cylindrical rod, the layer which suffers the mean strain and resists the load with the mean leverage being at a fixed proportionate distance from the axis, the diameter may be substituted for such distance; and it may be concluded that the advantage or leverage with which the matter of the shaft resists twisting is directly as the diameter of the shaft; the resistance is also directly as the quantity of matter strained, and hence as the area of the transverse section; therefore, by compounding, the area being as the square of the diameter, and the leverage as the diameter, in a solid cylindrical shaft the resistance is as the cube of its diameter; and in a hollow cylindrical shaft, as the difference of the cubes of its internal and external diameters. The extra strength gained by arranging the matter in the hollow form is evidently due to the removal of the matter to a greater distance from the axis, by which its strength resists the load with greater leverage. A hollow rod is said to be three times as strong in resisting torsion as a solid cylinder containing the same quantity of matter, and of a diameter such as to just fit the tube. The square section is found to be one-fourth stronger than the contained circular section; but as the area of the square is 1·7 that of the contained circle, and the leverage is greater in the square, while the torsional strength of the square section is only 1·25 that of the circular, it follows the circular section is the stronger form. This has been attributed to the fact that the corners of the square form projections unsupported by intermediate matter. If any leverage be given to the load by causing it to act through a lever attached to the rod or shaft, or through a wheel, the moment of the load or its efficiency to strain the shaft will be its weight or pressure multiplied by the length of the leverage, or the radius of such wheel. Tables of torsive strength give the

load (proof or ultimate), in pounds, of a rod of material having 1 square inch sectional area, such load acting through a leverage of 1 foot.

106. The torsional stiffness of similar rods, whether circular, triangular, square, or very long rectangles, is as the square of the sectional area, or, in other words, as the fourth power of their lineal dimensions; in rectangular rods of uniform section it is inversely as the product of the cubes of the transverse dimensions divided by the sum of their squares. The stiffness of a shaft is inversely as its length; for, if a length of 1 yard be twisted through $\cdot 25^\circ$ with a given force, 2 yards will be twisted through $\cdot 25^\circ + \cdot 25^\circ = \cdot 5^\circ$ with the same force, the total arc being the sum of the arcs through which each part of the rod is turned. In long shafts the angle of torsion is restricted below a definite limit of perhaps $\cdot 25^\circ$ per yard run. Thin rods subjected to torsion, as in shafting when long, require to be made thicker than the condition of torsional strength alone would indicate, in order to give sufficient stiffness—*e. g.*, wrought-iron shafts of less than 4·5 inches in diameter may require to be made heavier than requisite for strength to have sufficient stiffness, but above this size the stiffness does not demand special attention, as the shaft is stiff enough if strong enough. Additional strength is given to shafting to allow for sudden variations of load, caused by stoppage or starting of the machinery, &c.

107. The ultimate resistance to torsion varies with different materials between 1 and 1·5, that offered to cross breaking. The ultimate torsional strength of several materials is as follows:—

Steel, ...	1150 to 1900 lbs.
Iron, wrought, . . .	700 to 1000 „
Iron, cast, ...	650 to 750 „
Copper, wrought, . .	400 to 450 „

The comparative torsional strengths of several materials are—

Steel, ...	16·6 to 19·5
English iron, ...	10·1
Swedish iron, ...	9·5
Hard gun-metal, ...	5·0
Fine brass, ...	4·6
Copper, ...	4·3
Tin, ...	1·5
Lead, ...	1·0

The steel referred to is of different kinds—viz., shear, blister, Bessemer, &c., and high and mild qualities.

108. Shafting is not made taper, but is thinned in steps to fit

pulleys of fixed sizes, theoretical accuracy being sacrificed to convenience and economy. In making a rod subjected to torsion vary in thickness at different parts of its length, it is necessary that sudden variations of thickness be avoided. If a sharp shoulder be cut or cast on a shaft, the shaft is weaker at the shoulder than at any point in the thinner portion, or than a similar shaft equal in thickness to the thinner part, for the elasticity of the thick and thin parts are not equal, and the structure of the material is generally injuriously affected by the formation of the shoulder. Hence shoulders are not cut at right angles to the axes of shafts, but are rounded off so that the variation in thickness is less sudden, the thick and thin portions being connected by a segment inclined to both these portions.

109. In twisting wire and fibre to form rope, it is necessary to avoid twisting the material so much as to injure its elasticity, and thus weaken it; this fault is often committed in wire rope made by hand for stays or guys. Wire is much weakened by being subjected to torsion; hence, in paying wire on cable core, and in twisting wires into rope, it is necessary to avoid twisting the wires individually, whereby the tensile strength of the combination may be considerably reduced. In well made cables the wires are laid together without being twisted individually, this being done in the machine by causing the wire-supply drums to revolve round the core. In making a wire rope, however, the twist by which the wires are made to act together must be distinguished from the twisting of the individual wires; unless a certain obliquity be given to the wires with respect to the axis of the rope, the rope will be weak by reason of the stress being unequally distributed over its transverse section; the same remark applies to ropes of fibre, as hemp. A lashing of rope should, when necessary, be tightened by driving in a wedge, and not by inserting a lever and twisting the rope on itself; as the rope yarns are twisted in the rope, an additional twisting in the manner described is likely to weaken the rope by excessive twisting. But if a lashing be of fibre loosely twisted, it may be tightened by means of the twisting lever, and so tightened is less likely to work loose than if tightened by a wedge; while the pressure being more equally distributed, it may be employed where the use of a wedge is inadmissible. Wire lashing or serving should always be tightened by a wedge when practicable, in preference to twisting.

Section VI.—*Resistance to Transverse Load.*

110. When a piece of material is subjected to a force which bends it, and ultimately breaks it across, it is said to be broken *transversely;* and the load, strain, and stress are termed *transverse.* Only crushing and tensile forces are strictly longitudinal, and the several other modes of applying force to a piece of material are, strictly speaking, transverse; but bending and cross-breaking are termed so properly, and when transverse strength is referred to, unless expressly stated, resistance to shearing and twisting are excluded. A bar supported at two points, and loaded in a direction perpendicular or oblique to its length, is termed a beam; and generally any rod subjected to a transverse load, acts as a beam with respect to such load. A telegraph pole, strained transversely, and tied above the load, is analogous to a beam supported at both ends; an untied pole, loaded in the same manner, presents the case of a beam fixed at one end. Laws of transverse strength are generally referred to horizontal beams under the action of vertical loads; but no difficulty can arise in applying them to posts or beams strained transversely, in which the conditions are only modified by the beam being vertical or inclined, instead of horizontal, the force acting at right angles to the beam's length; in this case the difference is due merely to the mode in which the weight of the beam must be dealt with in calculating the gross load. If a rod be subjected to a force acting obliquely to its length, then such force must be resolved into its two components, one acting at right angles to the beam's length as a bending load, the other acting in the direction of its length as a tensile or compressive load; and these must be considered separately as two loads acting differently. A beam may be supported at both ends, fixed at both ends, or fixed at one end only; in the last case it is termed a *cantilever*, and by some authors the term beam is not extended to the cantilever; the term *girder* is applied in the first and second cases only. For the sake of simplicity, the beam will be assumed to be horizontal, and the load to act in a vertical direction.

111. A bar subjected to a transverse load is bent, one side of the bar becoming concave and the opposite side convex; on the concave side the particles suffer compression, and the beam on that side is shortened; on the convex side the matter is subjected to a tensile strain, and suffers elongation. Between the part suffering compression and that suffering extension is a plane in which the length of the beam remains unaltered during the action of the load—this is termed the *neutral plane;* the line in

which this plane cuts any section of the beam is termed the *neutral axis* of that section. When a beam gives way by bending and cross-breaking, the material is either crushed on the compressed side, or torn asunder on the stretched side; in general the length of the beam is such, compared with its thickness (Paragraphs 69 and 82), that the compressed side, when failure takes place on that side, fails rather by buckling than by direct crushing.

112. The resistance offered to destruction in this manner at any cross section is the moment of the couple, consisting of the thrust and equal and opposite tension. In any cross section the longitudinal stress is 0 at the neutral axis, and it increases with the distance from this axis to its maximum at the upper and lower edges of the section.

113. The case of a beam loaded below its proof load differs from that of a beam loaded beyond its proof load, in the relative areas of the parts into what the neutral axis divides any section. For loads less than the proof load the resistances of the material to extension and compression are sensibly equal, and the neutral axis divides any transverse section into two parts equal in area—*i.e.*, the quantity of matter suffering compression is equal to the quantity suffering extension, and the neutral axis passes through the centre of gravity of the transverse section. With a load exceeding the proof load, the resistance to compression and extension being no longer equal, the neutral axis divides the transverse section unequally; and at the moment of fracture the ratio between the areas subjected to pressure and tension respectively, in any cross section, is inversely as the ratio between the ultimate resistances of the material to pressure and to tension—*e.g.*, in a cast-iron beam, the resistance to pressure being six times the resistance to tension (approximately), at the moment of fracture the neutral axis would divide a transverse section into two parts having areas as 1 to 6; the area subjected to the ultimate tension being six times that subjected to the ultimate pressure. Only in a material having a compressive strength equal to its tensile strength would the areas above and below the neutral axis remain equal for loads exceeding the proof load.

114. It would appear from the above that the resistances of a material to pressure and to tension being known, its resistance to cross-breaking may be calculated; but in practice the resistance to cross-breaking is obtained by experiment, because circumstances, the effect of which cannot be calculated, operate to modify the result—*e.g.*, in cast iron instanced above, the casting being generally more rapidly cooled on the outside, cast-iron

beams are covered by a layer or skin of iron stronger than the internal iron, and, as will be shewn more fully below, this heterogeneity causes the transverse strength obtained by experiment to differ considerably from that obtained by calculation from the tensile and compressive resistances, on the assumption that the material is homogeneous.

115. The total longitudinal stress on each side of the neutral axis of a section is equal to half the load. The mean intensity of the stress on each side of the neutral axis is equal to the stress on that side, divided by the area. Generally in practice the stress at any point of a cross section may be assumed to vary uniformly and directly as the distance of the point chosen from the neutral axis; the position of the resultant stress then coincides with the centre of gravity of the figure on each side of the neutral axis, and is in amount equal to half the stress on the particles most distant from the neutral axis. From the above it appears the neutral axis is a fulcrum, pressure on one side of it being balanced by tension on the other. The efficiency of a particle to resist a bending load is greater the greater the leverage with which it acts—*i.e.*, its distance from the neutral axis. It is evident the matter near the neutral plane is not so efficient as that more removed to resist bending, as it cannot be so readily strained; for the extreme matter may be strained beyond its limit of elasticity before the internal matter has been strained up to that limit. Wooden beams are necessarily made rectangular in section; but in iron beams, the matter of the beam is concentrated as far as possible from the neutral plane, so as to attain the maximum strength with the minimum weight of material. Figs. 13 and 14 represent sections of iron beams fulfilling this condition more or less perfectly: the matter is concentrated in A and B, technically termed the flanges, the flanges are connected by C, the web. It is evident the whole bending stress is practically in the flanges, the functions of the web being to keep these apart, transmit the pressure between them, and resist shearing force (Paragraph 122). The whole matter of a beam acts with its maximum efficiency in resisting a load when the neutral plane is in the centre of the depth of the beam; under a load less than the proof load this is the case in a beam with flanges of equal sectional area; but when the ultimate load is approached, the resistance of the material to compression and extension being no longer sensibly equal, for the neutral plane to be in the centre of the depth, it is necessary in a flanged beam that the sectional area of the com-

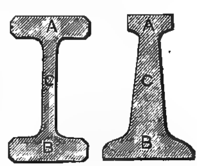


Fig. 13. Fig. 14.

pressed flange bear to that of the extended flange a ratio inversely proportional to the ratio of the compressive strength of the material to its tensile strength. Fig. 14 represents the section of a cast-iron beam, in which, the compressive strength of the material being about six times its tensile strength, the upper or compressed flange has only one-sixth the area of the lower or extended flange. As beams cannot be strained in practice beyond their proof strength—*i.e.*, their limit of elasticity, within which limit the resistances to compression and tension are equal, it has been contended with much reason that the flanges should be proportioned for working loads only—*i. e.*, should be equal, rather than proportioned for the ultimate load, which in practice can never be imposed.

116. The phenomena of cross bending being as described, it is evident if a solid rectangular beam be doubled in depth, its other dimensions and arrangements of its support remaining the same, the strength to resist cross-breaking will be doubled, by reason of the quantity of matter being doubled; and as this quantity of matter acts with twice its former leverage or efficiency, by reason of its mean distance from the neutral plane being doubled, the strength will be four times that of the original beam—*i.e.*, as the squares of the depths respectively. If the width of a beam be doubled, the other dimensions, &c., remaining unaltered, the quantity of matter in the beam is doubled; but this is simply equivalent to placing another and similar beam at the side of the original one, the matter added does not act with any additional advantage, the mean distance of the matter from the neutral plane remaining the same, in this case the strength of the original beam is doubled. The strength of beams is directly as their width, being directly as the quantity of matter strained, there being no access of strength due to increased efficiency of the matter of the beam—and as the square of their depth. Another mode of demonstrating that the strength of a beam is directly as the width, and as the square of the depth, is the following:—the strength of the beam at any cross section is directly as the moment of inertia of the cross section about its neutral axis; this moment is for each point in the section directly as the square of the distance of the given point from the neutral axis; the strength of the section is directly as the sum of the momenta of the points composing the section—*i. e.*, as the area of section multiplied by its depth, or as the product of the width by the square of the depth.

117. In flanged beams the web must be stiff enough to transmit the force without buckling; as the load rests on the upper flange, the force is transmitted through the web to the lower flange; the

web keeps the flanges apart, and acts as a short column. It is evident the web bears very little longitudinal tension and compression, these being mainly borne by the flanges; but the necessity for stiffness in the web so far affects the distribution of material, that it places a limit to that thinness in the web by which depth is gained, and the matter required to resist longitudinal tension and compression is placed as far as possible from the neutral plane, where it is most effective. In cast beams the calculated theoretical thickness of the web is exceeded, because great inequalities of thickness are not consistent with strength, from the difficulty in practice of cooling equally, large castings differing widely in thickness at different parts.

118. At least two forces are necessary to bend a bar, and these two forces must act at different points in the length of the bar. In a beam these forces are the pressure of the load, and the equal and opposite pressure of the supports. The pressure of the supports tends to shear the beam through, being a shearing force; both this and the pressure of the load are independent of any leverage, and act directly on the beam. The shearing force and the downward pressure of the load are necessarily equal; but while the force due to the upward pressure of the supports is greatest near the support, and diminishes towards the point of application of the load, the downward pressure of the load is greatest beneath the point of application of the load or its resultant, and diminishes to 0 at the points of support. The shearing force and direct action of the load form a couple whose moment is termed the *bending moment*, or *moment of flexure* of the beam, and is equal to the product of one of the equal forces into the distance between them—*i. e.*, the distance of the load from the support. In the case of a beam supported at both ends, the total bending moment may be considered as two couples, the load being conceived as divided between the two supports inversely as its distance from each support respectively. The bending moment is sometimes termed the moment of the load; it is really the moment of a couple of equal and opposite forces—viz., the upward pressure of the supports and the downward pressure of the load; it is the moment of the load about the outer point of support in a cantilever. In a beam supported at both ends, the load being conceived as divided into two inversely as the distances of the points of support, and the beam being conceived as divided under the load to form two cantilevers, each loaded inversely as its length, the bending moment is the sum of the moments of the loads about the points of support respectively (Paragraph 16). The bending stress due to the action of the couple or couples, formed of the upward pressure of

the supports, and the downward pressure of the load, is resisted at any section by the moment of the couple, consisting of the thrust and equal and opposite tension on opposite sides of the neutral axis, as already described (Paragraphs 111, 112).

119. The moment of a couple being directly as the length of its arm, the advantage or leverage with which a load acts on a beam must be directly as the length of the beam; and the strength of a beam is evidently *inversely* as its length, or the span.

120. The maximum shearing force in a beam fixed at one end and loaded at the other is equal to the load, and occurs close to the outer point of support; the shearing stress at any other section is directly as the distance of the given section from the loaded end. With a distributed load the shearing stress at any section of a cantilever is equal to the total load up to that section, measured from the outer end of the load—*e. g.*, in a beam of this kind loaded with 500 lbs. per foot, the shearing force 3 feet from the commencement of the load would be 1500 lbs., four feet 2000 lbs., and so on to the support, where it would equal the total load. The bending moment, being the shearing stress multiplied by the length of the section measured as above, is a maximum at the outer point of support; and the beam would break at this point with its ultimate load.

121. In a beam supported at both ends the shearing force is a maximum near the supports, where it is equal to the upward pressure of the support; and the total at both supports is therefore equal to the load. The shearing force at any section is less as the section is farther removed from the support, and under the centre of gravity of the load it vanishes entirely. To find this force at any section, subtract the load between the nearer point of support and the point of section from the pressure on the support; the difference is the shearing stress at that section. In beams supported at both ends, the maximum bending moment is in the centre, under the load, when the beam is loaded in the centre; and if the beam be loaded symmetrically the greatest bending moment will still be in the centre, where the beam would consequently break with its ultimate load. The bending being downward, the moment is of opposite sign to that of a beam fixed at one end, in which the bending is upward. It should be remarked, in a beam fixed at one end the maximum shearing force equals the load, and in a beam supported at both ends it can only equal the maximum pressure on one support.

122. The mean intensity of the shearing stress at any cross section is obtained by dividing the total stress by the area of the section. The stress is unequally distributed over the section,

being a maximum at the neutral axis, and diminishing towards the upper and lower surfaces of the beam, where it vanishes. It follows from this, in flanged beams the shearing stress is, practically speaking, borne by the web. In rectangular and cylindrical beams the resistance to shearing is much greater than that to cross-breaking; in cast-iron flanged beams the web is made stronger than necessary to resist the shearing action, because great inequalities of thickness render the casting weak; the web is made generally as thick as the top flange. In wrought-iron beams, in which the minimum of material required for strength can be attained, the resistance to shearing must be taken into account in assigning proportions to the web.

123. If a load be equally distributed over a beam, it may be considered as concentrated at its centre of gravity—*e. g.*, a beam fixed at one end will bear double the load uniformly distributed it will bear if concentrated at the unsupported end, for the distance of the resultant of the load from the support is halved by so distributing the load. A beam supported at both ends will, for the same reason, bear twice the load evenly distributed it will bear concentrated at its centre; it may be regarded as two beams supported at one end and acting together; the load may be considered as two loads, each half the total, and concentrated at one quarter the span from each support. If the load be not evenly distributed over the beam, then the bending moment, or the effect of the load on the beam, will be represented by the product of the two lengths into which the point of its application divides the beam, divided by the length of the beam, and multiplied by the load. The distribution of the load is equivalent to altering the point of action of its resultant, diminishing the advantage or leverage with which the load acts on the beam. The load which a beam will bear concentrated at any point in the beam, is to the load the same beam would bear concentrated in any other point, directly as the product of the lengths into which each load divides the beam respectively.

124. For a beam supported in a given manner, it has been shewn that the strength varies as the width and square of the depth of the beam directly, as the length inversely, and according to the position of the resultant of the load; it remains to compare beams supported in different manners. If a beam be supported at both ends and loaded in the centre, the upward pressure of each support will be equal to half the load; the maximum shearing stress will be equal to half the load; the maximum bending moment will be in this case half the load × half the span. In a beam fixed at one end and loaded at the other, the bending moment is equal to the whole length of the beam × the whole

load; hence, a beam supported at both ends and loaded in the middle is four times as strong as a beam of the same cross section and span fixed at one end and loaded at the other. The beam supported at both ends may be considered in this case as two cantilevers, each of half the span and bearing half the load. If the load be equally distributed in each case, the beam supported at both ends will still be four times as strong as that supported at one end only, and of the same length. A beam may be considered as a lever, and the action of the load and pressure on the supports evolved accordingly.

125. If a beam be fixed at each end instead of being merely supported, the fixing of the ends gives the beam additional stiffness. As its ends cannot rise, its upper surface near the supports is rendered convex when the action of the load depresses the centre, the fibres in the concave sides suffer pressure, and those on the convex, tension; thus, near the supports the upper fibres suffer tension and the lower fibres compression, and in the centre the reverse is the case, as in a beam only supported at both ends, the points A, B, fig. 15, dividing the curves, are termed points of contrary flexure; between these points the case is that of an ordinary beam supported at both ends, A and B; the shearing stress is greatest at A and B, and at these points there is neither pressure nor tension within the beam, but simply shearing stress; between each of the points of contrary flexure and the nearer support, the case is that of a beam fixed at one end and loaded at the other, and the shearing force is a maximum close to the support. Such a beam of uniform section should theoretically break at the ends, or in three places at once—viz., in the centre and close to each support, but never in the centre only. It has been contended that the fixed beam has twice the strength of a similar beam merely supported, because it may be regarded as having the strength of two fixed beams of half the span carrying half the load, in addition to the strength of the same beam merely supported at both ends, and that this much strength is necessarily used up in fracturing the beam in three places; but it has also been contended that the strain of the fibres at the centre is much greater than at the supports, and that only half the force is used up in causing the two end fractures, as in causing the fracture at the centre; therefore the beam with fixed ends is only half as strong again as the same

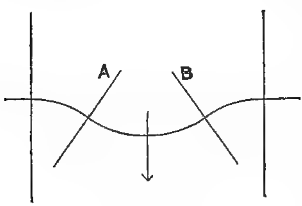


Fig. 15.

beam would be if merely supported and loaded in each case in the centre. The fixed beam may be conceived to be divided into three parts by the points of contrary flexure, each part acting as a separate beam; the parts near the supports are beams fixed at one end and loaded at the other, the load being attached at, and acting through, the points of contrary flexure; the central segment of the beam forms a small beam supported at each end by its attachment to the side portions. It is evident in the case supposed that the action of the load will depend on the positions of the points of contrary flexure; let these points be situated at one-fourth the span from the supports, the central part will be one half, the side parts one quarter the original span; the centre part considered as a beam will, having half the original span, bear double the load the centre beam would bear if merely supported; each of the side segments being one-fourth the original span will bear the same load as the original beam supported at both ends and loaded in the centre; hence the two together are twice as strong as the original beam so supported and loaded, and are together as strong as the centre segment; therefore the beam will fail at three places at once with its ultimate load, the three segments being equally strong. If the points of contrary flexure were nearer the supports than one-fourth of the span, the central segment would be weaker, and although the side segments would be stronger because shorter, the beam would fail in its weakest place (the centre), and would be less than twice as strong as if merely supported. This case cannot occur if the ends are properly fixed, for the side segments must in this case be at least as stiff as the centre. If the points of contrary flexure were nearer the centre than the supports, then the side segments would (considered as small beams) be increased in length, and their resistance would be diminished proportionately; in this case the fractures would occur at the supports, and the whole beam would be less than twice as strong as a similar beam merely supported at the ends and loaded in the middle. From the above reasoning it is concluded the *maximum* strength of a beam fixed at the ends, loaded in the centre, and uniformly stiff —*i.e.*, of uniform section, is twice the strength of a similar beam similarly loaded but merely supported at the ends; and the maximum advantage due to fixing the ends is only obtained when the fixing is perfect, a condition difficult to fulfil. The above conclusion agrees with the results of the most recent mathematical investigations, and is that generally accepted; some authors, however, state the strength of the fixed beam as low as once and a half, others as high as three times that of the merely supported beam. In bridges, the girders are fixed by

being made continuous from bay to bay. If a telegraph mast be fixed in the ground and guys be attached at the top, it resists a transverse strain as a beam; but for the bottom to be regarded as fixed it is necessary it be set in masonry or brickwork, because the distance to which such posts are buried, and the resistance of the earth near the surface are so small, that no appreciable increase of resistance can be calculated on with certainty as due to fixing in the earth. Even in brickwork or masonry the fixing is generally far from perfect, particularly when the joints are new or have deteriorated. A telegraph pole or mast stayed from the top and fixed in earth only, when subjected to transverse strain, must be regarded as a beam supported at each end. If a mast have two tiers of stays, it not only resists a transverse load better by reason of its being divided into two beams each of half the span, it offers a still greater resistance, for it presents a case like that of a girder continuous over two bays; one segment cannot be strained without straining the other, and there is consequently an increase of strength due to the increased resistance to flexure. As masts taper upwards, and are not therefore uniformly stiff at each section, the stays should not divide the mast into equal bays, but the length of each segment into which the attachments of the stays divide the mast, should be directly as the stiffness of the segment; thus, there should usually be a greater distance between the ground and the first tier of stays, than between the first and second tiers. Sometimes in a timber mast the positions of the stays are necessarily decided by other considerations, as the height of the mast-head or the position of a joint in the timber.

126. It is evident if a telegraph pole be regarded as a beam, its strength will be inversely as its height, directly as its width, and as the square of its depth; while, if stayed from the top, its strength will be increased at least four times, even if the straining force be applied at the centre of its length. It is evident that a rectangular post should be placed with its greatest transverse dimension in the direction of the greatest transverse strain—*e.g.*, in angle or terminal posts the greatest transverse dimension should bisect the angle or be in the line of strain respectively. From the above it is evident a post may generally be strengthened transversely cheaper by staying than by increasing its dimensions, and thereby adding to the quantity of material, cost of carriage, &c.; but if the transverse dimensions have to be increased by increasing the depth only when admissible, the additional material is applied to the greatest advantage.

127. The beams referred to above are solid rectangular beams;

the strength of cylindrical beams follows the same laws, being inversely as the length, and directly as the cube of the diameter. In a square beam, the width and depth being equal, these quantities may be considered together, and the cube of the depth or width may be substituted for the square of the depth multiplied by the width. The strength of a cylindrical beam is to that of a similar beam of square section of equal sectional area as 845 to 1000. The strength of a hollow cylinder or tube is to that of a solid cylinder of equal sectional area—*i.e.*, containing the same quantity of matter, as the difference between the fourth powers of the exterior and interior diameters, divided by the exterior diameter of the tube, is to the cube of the diameter of the solid cylinder. The strength of hollow uniform tubes, welded in lieu of being riveted, having circular, elliptical, and rectangular sections, was found to be as the numbers 13, 15, and 18 respectively; the material of which such hollow beams are made is generally wrought iron, and experiments on the strength of such tubes have been confined to that material. It is manifest from the above that masts are stronger with butt or welded longitudinal joints than with lap joints, because in the latter case the correct cylindrical form is necessarily departed from.

128. Beams are sometimes made in the form of tubes, the top of the tube corresponding to the compressed flange, the bottom to the extended flange, and the sides to the web, in the flanged girder; in such beams, when of very large size, the top and bottom are generally formed of a series of cells rather than of one piece—such a girder is termed a *tubular girder;* when the tube is smaller, and not cellular at the top and bottom, it is termed a *box girder.* Girders are sometimes made of a top and bottom flange, connected by lattice work formed of bars or strips; these strips form the web, and they are placed at an angle of 45° with the flanges, as this is the angle at which the shearing force tends to fracture the web. Telegraph and signal poles have been made combining the lattice and box girder principles; they are of square section, the corners are formed of angle irons, and the sides are filled in with curved flat iron. The idea is ingenious, but the flat metal being curved, and being placed with its width horizontal instead of vertical, the post is not so strong as it would be if the flat iron were placed on edge and in angles rather than in curves. Poles have also been designed strictly in accordance with the principles laid down, the corners being of angle iron, and the sides filled in with lattice work precisely like that in lattice girders.

129. Flanged iron beams are not used as a rule in telegraph practice; when iron posts of any special form are employed, the

strength is more easily and certainly decided by experiment, the maker should in such case understand the transverse strain the post should resist at its summit, or at a given height from the ground. No general rule can be given for determining the strength of a flanged beam of any form; experiments have to be made on each form of section, and thus a separate rule deduced for each form, by means of which, from the data obtained by experiment, the strength of similar beams of different dimensions may be ascertained by calculation. The rules for some of the commonest forms of flanged beams are given in Paragraph 331. The shearing force, its distribution, and the bending moment, may be found as described above; these particulars being independent of the form of section of the beam, the principles are applicable to beams of every form. The strength of lattice girders made up of top and bottom flanges, or booms, connected by lattice work of bars at 45° to the booms, may be calculated without sensible error by considering the tension and pressure borne entirely by the flanges, and the shearing force by the lattice web.

130. In calculating the strength of beams which are pierced for bolts, rivets, or similar fastenings, it is necessary to deduct the area of such fastenings from the area on which the transverse strength is calculated, if such fastenings are inserted in the portion of the beam suffering extension; but when fastenings occur in the compressed part of a beam, if the fastenings fit the holes made to receive them, they do not weaken the beam appreciably, for they offer the resistance which would have otherwise been offered by the original matter removed in making the hole. In riveting or bolting brackets or insulators to bridge girders, in boring poles subject to transverse strain for fastenings for ties, brackets, &c., in cutting mortises in beams and poles subject to transverse strain, and in all similar cases, the hole or mortise should be cut in the compressed part of the bar, and the bolt or tenon should fit well.

131. In increasing the strength of a beam by increasing its depth, it is necessary to join the pieces in such a manner that they cannot slide on each other when strained; for if two equal rectangular beams be placed together to form one of twice their common depth, and they be so connected as to act as one piece, the combination will be four times as strong as either taken separately, the strength being as the square of the depth. But if the two beams be simply placed together, when strained they will slide on each other like the plates of a carriage spring, and the combination will be only twice as strong as each beam separately. Telegraph poles are sometimes coupled in pairs when required to resist considerable transverse loads; in this case the

axes of the posts are placed in the line of direction of the load; and it is evident if the posts be joined so as to act as one post of twice the depth, the combination is four times as strong as either post by itself. Telegraph poles when coupled are usually separated by short struts, which keep them apart, and give a still greater increase of depth; in this case the combination is as strong as if the space between the posts were filled with solid matter, in fact this combination acts like a flanged girder. With the short distance between the posts generally allowed, the combination is about five times as strong as a single post; but to gain this advantage the straining force must act truly in the plane passing through the axes of the posts, and the connection between the posts must be such as to make them act as one piece. The latter condition is seldom fulfilled by iron posts coupled by clamps; in this case diagonal braces should be used to divide the plane between the axes of the posts into triangles, as in the lattice girder, in order to gain the maximum advantage from the increased depth.

132. As the bending moment or leverage with which a load acts on a beam is greatest in a cantilever near the support, and diminishes to 0 under the load, and in a beam supported at both ends greatest under the load and vanishes at the support, it is evident that equal strength is not required in every part of a beam's length; if therefore, a beam be uniformly strong throughout its length, there must be excessive material, in the cantilever towards the load, and in the beam supported at both ends near the support. Experiment proves this, for if uniform in section, the cantilever always breaks at the support, and the beam supported at each end under the resultant of the load. If the strength of a beam were so adjusted as to be at every cross section proportionate to the leverage of the load at that section—*i. e.*, to the bending moment at that section—then the beam would no longer tend to break always at the same place, but it would theoretically fail at every section simultaneously. Let AB (fig. 16) represent a cantilever, fixed at A, and loaded at B; as the bending moment or effect of the load is greatest at the end A, and diminishes towards B, it is evident the beam may be made thinner as B is approached, without in any way diminishing its power to support the load—*i. e.*, there is a waste of material if the beam be of uniform section from A to B, and the beam if uniform is really

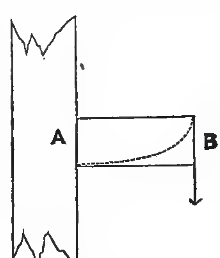


Fig. 16.

weaker than the same beam made thinner towards B, because the weight of the material of the beam forms part of its load (Paragraph 61), and the removal of all such matter as does not increase strength leaves a larger margin of strength to bear an external load. Part of the material of the cantilever may therefore be so removed as to diminish the depth gradually towards B, the width remaining the same, fig. 16; in this case the square of the depth at any section must be proportionate to the distance of the section from A; the lower surface of the beam should be curved, and the matter below the dotted line in the figure removed. The curve is a parabola, and one-third of the material of the beam may be removed without impairing its strength. The upper instead of the lower surface of the beam may be curved in the same manner with the same result.

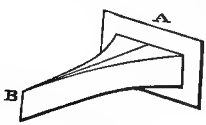


Fig. 17.

For a uniformly distributed load, the depth only being varied, the longitudinal section of the beam becomes a triangle with its apex at B. Instead of varying in depth, a cantilever may vary in width, the width being made proportionate to the bending moment at each section; in this case, with the load at B, the plan of the beam is a triangle with its apex at B; with a uniform load the plan is two parabolas touching at B, fig. 17.

133. A beam supported at both ends may have its width or depth varied in a similar manner, according to the mode of application of the load; for a load concentrated at any section, the product of the width into the square of the depth at each section must be made proportionate to the distance of the section from the adjacent point of support. If the depth be constant, the width being varied, the plan of the beam becomes two triangles having their common base under the load, and their apices at the points of support; if the depth only be varied, the longitudinal section presents two parabolas meeting under the load, and having their vertices at the points of support. With a uniformly distributed load, the product of the width into the square of the depth at any section being made proportional to the product of the distances of the section from the points of support, the longitudinal section with constant width is an ellipse; and the plan, the depth being constant, presents a pair of parabolas having their vertices in the middle of the length of the beam, and their common base in the middle of its width. From the above it appears a beam may be made sharp where the bending moment vanishes, but this cannot be done, because the shearing force must be resisted; hence the bearing surface of the beam must be sufficient to resist the shearing force, irrespective of its

resistance being proportioned at each section to the bending moment. For this reason, in practice beams are made extended at the bearings to resist the shearing force and to prevent the beam turning. In practice the taper is not always confined to one dimension; in some cases both the width and depth are varied in order to proportion the strength of the beam at each section to the moment of flexure, the total variation being divided between the width and depth. Long crane jibs and shear-leg poles are bent like beams, and the best form for these is that of a parabolic spindle; this is the form a beam would assume if its cross section were circular, and its resistance at every section made proportional to the bending moment. Sometimes a conical spindle is used, as approaching the parabolic form near enough in practice. In such a beam the ends should have two-thirds the area of the greatest section. The variations of width, depth being constant, are applicable to flanged girders of the T and double flanged sections. The tapering of beams is of great importance in metal beams, particularly when of great weight, as there is a proportionate saving in expense of manufacture and carriage, and additional available strength. Timber beams may be strengthened by adding smaller timbers, so as to increase the depth proportionately to the bending moment at each section, such practice being much more economical than adding to the thickness of the beam throughout its entire length.

134. Telegraph poles subjected to transverse strain should not be uniformly strong throughout their length: a pole fixed in the ground and unstayed should diminish in strength towards the top, and should have about two-thirds the strength at the point of application of the load it has at the base. The proportions of tied and strutted poles should also be regulated by the principles stated for beams. If an unstayed pole be too much tapered it will break with its ultimate load above the ground line; the proportions should place the breaking point at the ground line; therefore a timber post should not have a less cross sectional area at the point of application of the force than about two-thirds that at the ground line. A post if too weak should be strengthened in accordance with the above principles, by the addition of material, not necessarily through its whole length, but distributed proportionately to the bending moment at each section. It should be remarked, in iron-plate posts of large size, if the plate be very thin compared with the diameter of the tube, the tube is stronger as its diameter diminishes; therefore, as the diameter of the tube decreases upwards, the gauge of the plate may be reduced where less strength is required. Thus, a mast in which the lowest segments are of

$\frac{1}{4}$-inch plate, may have upper segments of $\frac{1}{8}$-inch plate with advantage, both on account of the smaller diameter of the upper segmental tubes, and by reason of the bending moment being less above than below.

135. The laws of strength in beams have been stated without reference to the weight of the beam; but the weight of the beam itself, when acting with the load, must be added to the external load to form the gross load, to bear which the strength of the beam must be proportioned. If the weight of the beam be small compared with the external load, as in short timber beams, the weight of the beam itself is neglected; but in heavy metal beams the weight of the beam cannot be neglected with safety—*e.g.*, a cast-iron beam may use up one-fourth of its available strength in bearing its own weight. It is usual to design the beam provisionally to bear the external load only, then to calculate the weight of the beam, and increase the strength to bear the gross load, if the weight of the beam compared with the external load renders such increase necessary. In the case of a telegraph pole subjected to a transverse load, if the pole be vertical and the direction of the load horizontal, the weight of the post forms no part of the transverse load.

136. If a beam be inclined to the load, as in figs. 18 and 19, the lines A B perpendicular to the load represent the reduced

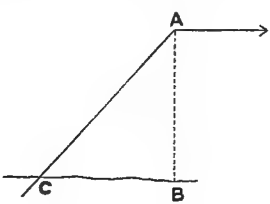


Fig. 18.

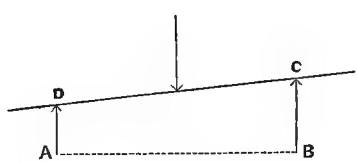


Fig. 19.

span on which the transverse strength of the beam should be calculated; in fig. 18 the inclined beam is stronger than a beam of the same length perpendicular to the load in the ratio AC : AB, the effect of inclining the beam being to reduce the span. For example, if CA, fig. 18, represent a post loaded at A, the resistance of the post would be that of a similar cantilever of length AB, placed in the line AB. If fig. 19 represent a beam supported at each end, and loaded in the centre or elsewhere, its resistance is that of a beam of similar section perpendicular to the load and equal in span to AB. The case shewn in fig. 18 is presented by an angle post, the tie or strut of which has been accidentally removed; the post then gives to the load, until, by

reason of the decrease of leverage to AB, the compression of the earth, and the slacking of the line, equilibrium is established between the forces acting on the post. It is evident in the cases considered the load may be resolved into two components, one acting in the direction of the beam, and one at right angles to its direction; the former component only producing bending stress, the latter producing pressure or tension in a cantilever, or pressure towards one support and tension from the other, in a beam supported at both ends.

137. The transverse strength of different materials is obtained by experiment; the numbers given in tables of transverse strength signify the ultimate load in pounds acting in a direction at right angles to the beam's length, concentrated at the centre of a bar of each kind of material 1 inch wide, 1 inch deep, and supported on supports 1 foot apart. With the data supplied by such a table it is evident the strength of any beam of simple form of section, given dimensions, arrangement of supports, distribution of load, and nature of material, may be readily calculated approximately from the principles enumerated above—the constants being used with caution, and experiment and observation being preferred when attainable.

138. The deflection with a given load of any point in a beam is the displacement of that point from its position when the beam is unloaded; the deflection of the beam is that of the point in it which suffers greatest displacement. When the load is less than the proof load, the deflection of a given beam is nearly proportional to the load; but when the proof load is exceeded, the deflection increases irregularly, and in a greater ratio than the load is increased. For loads not exceeding the proof load: The deflection of solid rectangular beams of the same material, and under equal loads, similarly distributed, varies directly as the cube of the length, and inversely as the width and cube of the depth. The deflection of solid cylindrical beams is directly as the cube of the length, and inversely as the fourth power of the diameter. The deflection in flanged girders is directly as the sum of the areas of the cross sections of the flanges, as the cube of the length, and inversely as the product of the areas of the cross sections of the flanges and the square of the depth of the web. Stated generally, the deflections of similar beams of the same material, under equal loads, similarly distributed, are directly as the cubes of the lengths, and inversely as the breadths and cubes of the depths.

139. Under proof loads, the deflection of similar beams of the same material is as the squares of the lengths, and inversely as the depths, the loads being similarly distributed.

140. The deflection of a beam fixed at one end and loaded at the other is equal to that of a beam of the same material and section, supported at both ends, of twice the length, bearing double the load at its centre—*i.e.*, a cantilever loaded at the end is deflected sixteen times as much as the same beam would be deflected, if supported at both ends and loaded in the centre with the same load.

141. If the load be uniformly distributed over a beam supported at both ends, the deflection is only five-eighths that which the same load would cause if concentrated at the centre of the same beam. The deflection of a beam fixed at one end, and uniformly loaded, is three-eighths that the same load would produce if concentrated at the end of the same beam.

142. If a beam be bent beyond a certain point, its elasticity is injured, a sensible permanent set is produced, and the beam is weakened; if the application of the excessive load be repeated, the beam will sooner or later fail. It is necessary, therefore, that the deflection of a beam never be allowed to exceed a certain proportion of the span; this proportion is, for timber about $\frac{1}{480}$, cast iron $\frac{1}{130}$, wrought iron and steel $\frac{1}{500}$; if these proportionate deflections be exceeded, a permanent set is produced. In practice the deflection varies for the proof load between $\frac{1}{200}$ and $\frac{1}{600}$, and for the working load between $\frac{1}{600}$ and $\frac{1}{1500}$ of the span. The necessity for limiting the deflection, and the fact that rigidity decreases in a greater ratio than mere strength, renders it advisable in designing beams to decide upon the depth necessary to give the required stiffness, and then proportion the width so as to give the necessary strength; this is the order generally followed.

143. The deflection in any particular case may be calculated from the constants given in the following table:—

	Constant.
Elm,	1,620
Larch,	2,437
Pitch Pine,	2,837
Riga Fir,	3,079
Beech,	3,133
Oak (English),	3,359
Mahogany (Honduras),	3,571
Ash,	3,807
Deal (Christiana),	4,176
Red Pine,	4,259
Deal (Memel),	4,500
Iron, Cast,	41,740
„ Wrought (Swedish)	64,221
Steel, Hammered,	78,822

The constants for wood are given on the authority of Messrs. Barlow and Tredgold respectively, that for cast iron on the authority of Mr. Banks, and the last two on that of Mr. Kirkaldy. In practice the amount of deflection should be obtained, if possible, by experiment or observation of similar girders of the same material. Constants should be applied with great caution (Paragraphs 67 and 299).

144. By means of the following formulæ may be calculated the strengths and deflections of beams of simple forms. Let l, b, and d represent the length, breadth, and depth of a beam respectively, w its ultimate load, c the constant of transverse strength for the particular material—this constant being the ultimate load of a bar one inch square in section, supported at points one foot apart, and loaded in the centre; m, a factor dependent on the arrangement of supports; m_1, a factor dependent on mode of distribution of load; then

$$w = \frac{d^2 \times b \times c \times m \times m_1}{l}$$

$m = 1$ for a beam supported at both ends, and $\frac{1}{4}$ for a beam fixed at one end;

$m_1 = 1$ for a load in centre of beam supported at both ends, or at end of cantilever; and 2 for a load equally distributed;

w, divided by a suitable factor of safety, is the working strength. If the ends of the beam be fixed, instead of supported, a factor m_2 should be introduced into the second member of the equation, the maximum value m_2 can have is 2. Let x be the constant of deflection; this constant is the quotient of the ultimate load in pounds by the ultimate deflection in inches, the bar being one inch square in section, supported on supports one foot apart, and loaded in the centre—a table of these constants is given above, Paragraph 143; c_1 the deflection in inches, and w_1 the load; n, a factor dependent on the arrangement of the supports, and n_1, a factor dependent on the mode of distribution of the load; then, under a load not exceeding the proof load—

$$c_1 = \frac{l^3 \times w_1 \times n \times n_1}{b \times d^3 \times x}.$$

With both ends supported $n = 1$; with one end fixed $n = 16$; with the load in the centre of a beam, supported at both ends or at the end of a cantilever, $n_1 = 1$; when the load is evenly distributed $n_1 = \frac{5}{8}$ for a beam supported at both ends, and $\frac{3}{8}$ for a

cantilever. If a beam be firmly fixed at both ends the deflection is reduced to one-fifth of that of a merely supported beam. The above formulæ apply to rectangular and cylindrical beams; the constants apply to beams of square section, and must be multiplied by $\frac{10}{17}$ to render them applicable to beams of circular section. The formulæ are applicable to beams of any section, but not the constants; hence similar beams of any given form of section may be compared by means of the formulæ; and their strength and deflection may be ascertained, if the constants be previously ascertained by experiment for the particular form of section. The following is a more general rule for finding the deflection of a beam:—

$$c_1 = \frac{w, \times l^3}{48 \times \varepsilon \times \mathrm{I}};$$

ε = modulus of elasticity of the material;
I = moment of inertia, of the section of rupture, or of the section of the beam if of uniform section (Paragraph 32).

CHAPTER III.

GENERAL PRINCIPLES OF EQUILIBRIUM AND STABILITY.

SECTION I.—*Frames.*

145. A STRUCTURE is composed of solid materials, which may be either stiff, as stone, wood, &c., or loose, as earth, sand, &c., the pieces of material being put together so as to preserve the form of the structure and arrangement of its component pieces, under the conditions to which the structure must be subjected while fulfilling its purpose. The several solid bodies composing a structure are termed its pieces; the surfaces at which the pieces touch each other and are connected together are termed joints. If the structure be fixed relatively to the earth, the portion of the solid matter of the earth which immediately supports it is termed its foundation.

146. In order that it may fulfil its purpose permanently and efficiently, a structure must possess due *stability*, *strength*, and *rigidity*. Stability consists in the forces acting on the structure

as a whole, and likewise those acting on each component piece of the structure, being balanced. These forces are, in the former case, the weight of the structure, the external forces, and the upward pressure of the earth; in the latter case, the weight of the piece, the external forces acting on it, and the forces acting between it and the adjacent pieces in contact with it. Strength consists in the forces acting between the parts of each piece of a structure into which the piece may be conceived to be divided, balancing each other. Rigidity or stiffness is intimately connected with strength, and both qualities are necessarily considered together; as defined in Paragraph 50, it is that quality of bodies or structures by which they resist change of figure. In forming a structure the material and dimensions of each piece, and the manner of combining the pieces into a structure, must be such that the alteration of figure of each piece and of the whole structure may be confined within certain limits, under every possible set of conditions to which the structure may be subjected. In the term force, it should be remarked, the upward pressure of the earth supporting the structure, and the power by which bodies resist forces tending to fracture them (stress), are included.

147. A structure composed of bars or rods, or these combined with cords or chains jointed together, is termed *a frame*. In small works, as in joinery, the strength of the work is often dependent on the resistance offered by the joint to change in the relative positions, at the joint, of the pieces connected; but in framework, both of wood and metal, of considerable size, constructed to withstand great loads, in general the rigidity of the joints does not contribute sensibly to the strength of the structure, and the bars, &c., may be regarded as movable about the joints, as if hinged there. Very little consideration will render evident the fact, that in the majority of frames constructed to bear considerable loads, the length of the bars affords so great a leverage to forces tending to disturb their relative positions, that it would be impracticable to make the joints strong enough to offer appreciable resistance to destruction or distortion of the frame by movement of the bars about the fastenings; the rigidity of such frames is necessarily dependent on the *arrangement* of the component bars and cords.

148. The stress in the component bars of a frame is a distributed stress distributed through their mass; its intensity is measured as explained in Paragraphs 24 and 50. Forces acting on the component bars of a frame tend to displace the bars relative to each other at the joints where they meet; this tendency to displacement is resisted by the stress at the joint. The point in the

joint through which the resultant of the resistance passes is termed the centre of resistance of the joint. It is evident the maximum strength of the material cannot be available if the position of the centre of resistance of the joint deviate much from the centre of figure of the joint. If the centres of resistance of the joints be conceived to be connected by lines, the system of lines is termed the line of resistance of the frame. The loads on the joints and the component bars of a frame, and on the points of support when the frame is supported, are computed by considering the distributed forces acting on each bar or joint as concentrated in the line of their resultant or resultants acting through the centres of resistance; and by compounding and resolving these resultants at the centres of resistance by the parallelogram of forces or theory of couples; the total loads and stresses being found, the intensity of the distributed force is found by dividing the resultant by the surface or mass over which it is distributed.

149. The component bars subjected to transverse strain are termed *beams*, those suffering tensile strain *ties*, and those suffering compression *struts*—terms already defined in Chapter II. The action of a load on a tie, strut, and beam, and the mode of failure of each under an ultimate load, are fully considered in Chapter II. It is evident if a strut be movable, that its longitudinal equilibrium is unstable; for, if its axis deviate from the line of direction of the pressures it resists, these pressures form a couple acting to increase the deviation from the line of pressures, fig. 20. If a tie be movable, its equilibrium is stable. This case is represented by fig. 20 with the directions of the forces B and C reversed, A representing the tie. If A, the tie or strut, lie in the line of action of the forces B, C, then the whole of these forces are resisted by the longitudinal stress on the rod A—*i.e.*, the sum of the forces is employed in longitudinal tension or pressure of the rod A. If A be at right angles to B, C, then there is no longitudinal tension or pressure on A. At intermediate positions, as in fig. 20, the forces B, C may each be resolved into two rectangular components, one acting in the direction of A (2, 3), producing tension or compression of A, the other (3, 4) acting at right angles to A, forming one arm of a couple tending to rotate it on its centre. It is evident the arm of the couple referred to above is as the *sine*, and the efficiency of the tie or strut as the *cosine* of the angle 1, 3, 2 between the common direction of the forces and the line of resistance of the tie or strut. A strut requires therefore that care be taken to place

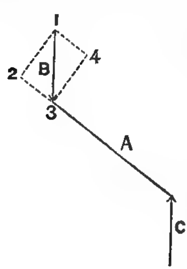


Fig. 20.

it exactly in the line of the pressures to be resisted; and when so placed, that means be taken to prevent deviation from this line. A tie may be employed without such special care or precaution, its equilibrium being stable; hence, in constructing land lines the tie is preferred, where admissible, to the strut. Struts are frequently stayed to prevent them deviating from the position of greatest efficiency. A stay is a rod or cord applied to the end of a strut or tie to keep this end in position, and prevent deviation of the strut or tie from the line of action of the load, the stay merely keeping the strut or tie in position under the action of the load, and not itself bearing any portion of the load. An instance of staying is presented by a high telegraph mast supporting a direct wire, furnished with stays stretched from near its summit to the ground; but in an angle post the tie generally employed to act with the post in resisting the horizontal strain of the lines is not properly a stay but a tie; for it bears in general its share of the load, and forms part of the frame composed of the tie and strut attached to the earth. In Chapter II., section 6, the case of a beam having the load and supporting pressures parallel is treated, and also the case of a beam placed obliquely to the load and supporting pressures; in the latter case, the load being resolved into two rectangular components, one acting in the direction of the beam's length, the other acting perpendicular to its length, the magnitudes of these components represent the longitudinal and transverse stresses respectively. If the load be inclined to two parallel supporting pressures some fourth force must balance the longitudinal load, and in respect to such load the bar is a tie or strut, or tie on one side of the point of application of the load and strut on the other side. When the supporting forces and the load are inclined to each other, the conditions of equilibrium are those of three inclined forces (Paragraph 6). If AC, fig. 21, represent a bar acted upon by three forces (A, B, C) in equilibrio, the relations of the forces are those of the sides of the triangle 1 2 3, drawn proportionate to the balanced forces in magnitude, and parallel to them respectively in direction; and the magnitude of each force is as the sine of the angle between the other two.

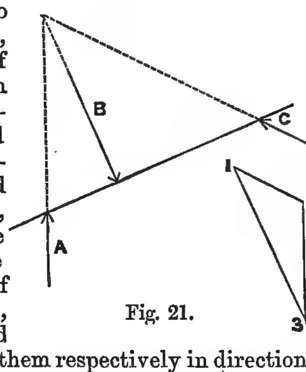


Fig. 21.

150. A frame of two bars may be composed of two struts, two ties, or a tie and a strut, and must abut against, or be connected

with, two fixed points. If fig. 22 represent a frame of two ties attached at A and B, and loaded at C, the load on each bar and on the supports is found by resolving the load into two components, Cd, Ce, acting in the directions of the bars, and representing the load on each bar and on the supports, both in direction and magnitude. The equilibrium is evidently stable, both in the plane of the frame and at right angles to that plane, as deviation in either direction must raise the load; but the system may oscillate about A and B, and may need staying to prevent this.

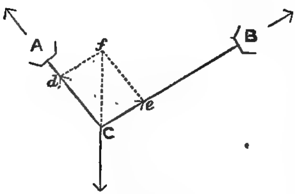


Fig. 22.

151. If the diagram be inverted and the arrows reversed, the case represented is that of a frame of two struts, and the load on each bar and the supports is found as before, pressure being substituted for tension. In this case the position of the bars is fixed in the plane of the frame; but in the plane at right angles to this the equilibrium is unstable, unless lateral stays be employed to render it stable. An upright pair of shear legs furnishes an instance of a stayed frame of two struts; an angle pole strutted to the top is an instance of an unstayed frame of this kind. An angle pole with a short strut applied below the load may be considered as a bar acted upon by three inclined forces—viz., the external load, the pressure of the earth, and the pressure of the strut (fig. 21, Paragraph 149).

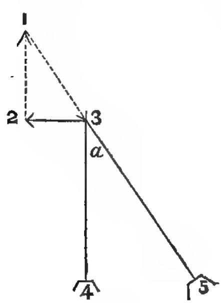


Fig. 23.

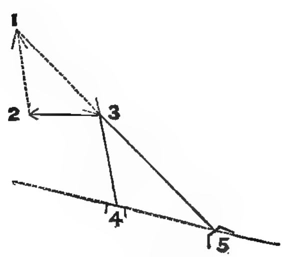


Fig. 24.

152. Frames formed of a strut and a tie are of very common occurrence in telegraph practice; an angle pole and tie (sometimes called a stay) furnishes an instance of this kind of frame.

In this frame, as in other two bar frames, three inclined forces are balanced, and their relations must fulfil the conditions of the triangle of forces (Paragraph 7). The load being determined, it is resolved into two components acting in the directions of the two bars respectively; these components represent the load on each bar, and the pressure and tension on the supports. The conditions are those of three forces in equilibrio, the load being balanced by the stresses on the bars. Figs. 23, 24, and 25 represent three cases; the stress on each bar is directly as the sine of the angle between the direction of the load and that of the other bar; thus, in the figures, the load 2 3, divided by the sine of the angle between the bars, equals the stress on either of the bars divided by the sine of the angle between the direction of the load and that of the other bar.

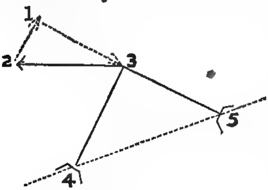


Fig. 25.

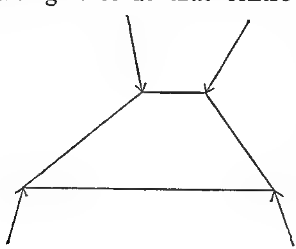
Symbolically—

$$\text{Load} : \sin 1 :: \begin{cases} \text{component } 1\ 2 : \text{sine } 3 \\ \qquad \text{or} \\ \quad ,, \quad 1\ 3 : \text{sine } 2; \end{cases}$$

the load on each bar may be readily found from the proportion, the load on the frame and the angles being given. Fig. 23 represents the case of an angle pole placed perpendicularly and tied; sine $90° = 1$, therefore the component load borne by the tie is the quotient obtained by dividing the load by the sine of the angle between the strut and tie. The efficacy of the tie is therefore as the sine of the angle it makes with the strut; thus, with the angle $a = 30°$ the component load (1 3) on the tie is double the load 2 3; with the angle $a = 90°$ this load is only equal to the load 2 3; while with angle $a = 14°$, the tie suffers a tension four times the horizontal load 2 3. The component load borne by the strut is also greater as the angle a is diminished; thus, for $a = 14°$ this load is 4 times 2 3; for $a = 30°$ it is 1·7 times 2 3; and for $a = 90°$ it is 0, the whole load being borne by the tie. The necessity for anchoring the tie a proper distance from the foot of the mast or post to be tied is evident. It is evident the supporting forces at 4 and 5 are equal and opposite to the loads on the bars respectively, found as above. A frame composed of a tie and strut is stable in the plane of its lines of resistance, but it is only stable laterally when the direction of the load inclines from the line 4 5, joining the points of support; thus, fig. 24 is unstable, and fig. 25 stable, laterally. The frame, fig. 25, is rendered stable laterally by being stayed on each side. The

mode employed above of finding the pressure and tension on each bar is equally applicable whether the frame of two bars form an independent frame, or two bars in a more complex frame.

153. In a frame of three or more bars the same laws apply as in less complex frames; but if the bars form a closed figure, the forces supporting the frame as a whole have to be computed in a somewhat different manner to that given above. In general the supporting forces may be found by considering the frame as a whole, and finding the resultants acting through the points of support, as in the case of a simple beam; if a centre of resistance be also a point of support, the component load at such centre acting through the point of support must be neglected until the components at the other points have been found, and then the resultants of all these acting through the points of support are equal and opposite to the supporting forces. If a load be applied at a centre of resistance which is also a point of support, then the component of such load acting directly through the point of support must be added to the pressure of the frame on that point of support, and an equal and opposite force must be combined with the supporting force at that centre to complete the solution.



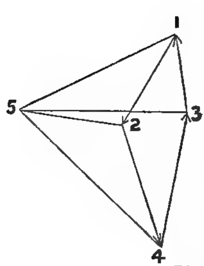


Fig. 26.

The conditions of equilibrium in a frame of three or more bars are obtained graphically by two simple operations, by which are found—*Firstly*, the system of forces which would balance each other if applied at the centres of resistance; and, *secondly*, the system of stresses on the several bars of the frame. The forces applied at the centres of resistance being balanced must obey the laws stated in Chapter I., section 1, and, if represented by lines, the lines will form a closed figure (triangle or polygon of forces); if in a projected frame the lines representing these forces do not form a closed figure, then the line or lines necessary to complete the figure

represent the force required to produce equilibrium. If the system of forces be given, a diagram of stresses can be made to resist the forces; if the diagram of stresses be given, the system of forces is also given. Let fig. 26 represent a frame of four bars acted upon by a system of inclined forces applied at the centres of resistance; the forces being balanced, if they be represented by lines parallel to their directions, such lines will form a closed figure (Paragraph 8, &c.) Let 1 2 3 4 be such a closed figure, from 1, 2, 3 and 4 draw lines parallel to each bar of the frame respectively; these will meet in 5, and represent the stresses on the bars to which they are respectively parallel, due to the system of forces represented by 1 2 3 4. It is evident that, given a system of forces 1 2 3 4, a system of stresses can be designed to resist it; and given a system of stresses, the forces such will resist are obtained by joining the extremities 1 2 3 4, of the lines 5 1, 5 2, &c. If from any point 5, lines be drawn parallel to the sides of a frame, and proportionate in length to the working stresses of the several bars respectively, the maximum load which may be safely applied at each centre of resistance is found by completing the figure 1 2 3 4. Frequently in practice a system of parallel forces forms the subject of the calculation; in this case the figure 1 2 3 4 becomes a straight line. Let ABC, fig. 27, represent the lines of resistance of a triangular frame, bearing a vertical load at 1, and supported at 2 and 3; draw the line AC, fig. 28, equal to the load at 1, and divide it at B into AB, and BC = the supporting forces at 3 and 2 respectively; if from A, B, and C lines be drawn parallel to the sides of the triangle 1 2 3, these lines, CO, BO, AO, represent the stresses on the bars to which they are respectively parallel; the segment AB represents the force applied at the joint between the bars to which OB, OA are respectively parallel, and BC the force applied to the joint between the bars to which OC and OB are respectively parallel; and the segment of AC intersected between any two of the radiating lines contiguous or not, represents the resultant of the external forces acting between the bars whose lines of resistance are parallel respectively to the lines selected. The vertical line AC represents the vertical load; and if a line OH be drawn from O perpendicular to AC, it represents the horizontal component of each of the stresses OC, OB, OA—*i. e.*, if each of the stresses OC, OB, OA be considered as resolved into two rectangular components, respectively

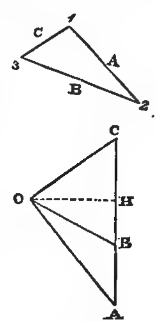


Fig. 27.

vertical and horizontal, the horizontal components will be equal to each other and to the line OH—hence termed the horizontal thrust, stress, or resistance of the frame. Trigonometrically, the horizontal stress OH is equal to the load AC, divided by the sum of the tangents of the angles made by any two lines of resistance and the horizontal line, the angles being taken in the same direction; and by the difference of the tangents if the angles be taken in opposite directions. The stresses on the bars of a frame, whether the bars be contiguous or not, are respectively as the horizontal stress multiplied by the secants of the angles between the lines of resistance of the bars and the horizontal line.

154. If the bars of a frame do not form a closed figure the extreme bars must be attached to fixed bodies, if the fixed bodies resist a thrust they are termed abutments. The stresses in an open frame are found as in the case of a closed frame; but the diagram obtained is necessarily rendered simpler by the omission of the bar necessary to complete the closed figure. The formulæ and diagrams given are applicable to open frames, if it be remembered that in the latter case the stresses on the extreme bars have to be balanced by the pressure of the supports—*i. e.*, the supporting forces are equal and opposite to the stresses on the extreme bars, as described in the cases of two bar frames. In fig. 27 the bars 1 2, 1 3, are struts; but if the frame be reversed, so that 1 is downwards, these become ties; and generally, the diagram of a frame is not altered by such reversal, but the struts become ties and the ties struts—*i. e.*, the distribution of the forces remains the same, but tension is converted into pressure, and *vice versâ*. A triangular frame of three bars, as fig. 27, is rigid in the plane of the bars—*i. e.*, its form cannot be altered by turning of the bars about the joints; but a frame of four or more sides, having hinged joints, may be altered in figure by the turning of the bars about the joints; and to render such a frame rigid it is necessary that it be divided into a series of triangles, or triangles and polygons, so that each figure of four or more sides be surrounded on all sides but one by triangles. A triangular frame, or a polygonal frame, rendered rigid by division into triangles, &c., as described above, is termed a *truss.* In practice, when the load is subject to small variations only in its mode of distribution, frames are not always stiffened completely by the mode of division into triangles; sometimes the frame being only partially so stiffened, the inflexibility of one or more of the bars or joints is relied on to complete the degree of rigidity required; and manifestly if a frame contain a figure of four or more sides, not surrounded on all sides but one by triangles, such frame

must owe its rigidity more or less to the rigidity of its joints or bars.

155. It has already been pointed out how by means of a diagram of forces a frame may be designed to resist a given set and arrangement of forces, but generally in practice the load is subject to variation both in its amount and mode of distribution; hence the necessity for so stiffening the frame that it may not only resist distortion under a given load, but also under various modes of distribution of load; to accomplish this end bars are introduced, termed stays and braces. The functions of stays have already been described: a brace is a bar which may act as a tie or a strut, or both alternately; it joins two joints in the frame, and introduces two equal and opposite forces acting on the joints along its line of resistance; these forces being equal and opposite, the resultant of the forces applied to the pair of joints joined is not affected thereby either in amount or direction. If the forces acting on a frame as a whole balance each other, there is no tendency for the frame as a whole to move; but unless the forces acting on each bar separately balance each other, there will evidently be motion of the bars relative to each other—*i. e.*, the frame will suffer distortion. The introduction of a brace merely alters the distribution of the forces amongst the several bars, to produce the necessary equilibrium in each separate bar. The necessity for bracing is shewn by the diagram of forces; for the lines representing the stresses on the several bars do not in such case meet in one point, as in figs. 26 and 27,

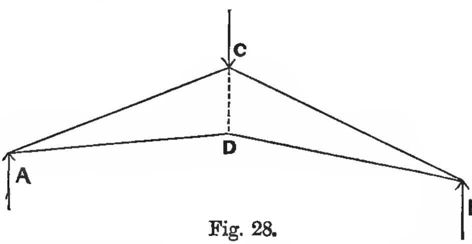


Fig. 28.

but in two or more; and the lines joining these points represent the direction of and stresses on the braces required to bestow rigidity on the frame. Let fig. 28 represent a frame of four bars supported at A and B, and loaded at C; it is evident on inspection, although the forces ABC acting on the frame as a whole may be in equilibrio, the forces acting on the separate bars are not so; for the action of the forces A, B, and C, is to flatten the frame until the bars AD, DB are in the same straight line, and

the frame acts as a frame of three bars only, AD and DB forming in this case a single tie. Let fig. 29 represent the diagram of forces drawn as in fig. 27, AB will represent the load, BC, AC the supporting forces acting on the whole frame; the inclined lines A2, B2, &c., represent the stresses on each of the bars of the frame to which they are respectively parallel; but these lines do not meet in one point only, they meet in two points, 1 and 2, the line joining these two points represents the direction of and load on the brace CD, fig 28. This mode of determining the particulars of braces may be applied in the same manner to frames of greater complexity. The frame, fig. 26, has evidently no tendency, as in fig. 28, to change its figure; but as it has four sides, it is evident that although in equilibrio the sides AB, CD, are free to change their positions, and unstable. To render them stable it is necessary to divide the frame into triangles, in this case the bar introduced is not a brace but a stay; it does not resist a permanent load, but merely retains other bars in position; for in the diagram of forces the lines drawn parallel to the bars of the frame meet in one point, shewing the absence of the necessity for bracing. The equilibrium of bars forming parts of a frame is the same as in the cases of single ties and struts and two-bar frames; it is manifest the combination of bars into a frame does not modify the conditions of equilibrium of each single bar. A polygonal frame is only stable in the plane of its lines of resistance when it is so divided by stays or braces, or both, that it cannot change its figure—*i. e.*, when the ends of the struts are fixed by stays or otherwise, and when the component forces acting on each bar are balanced, either by reason of the form of the frame or by the application of braces. Frames may be so connected that a bar may at the same time form part of two frames; in this case the forces acting on the bar due to its forming part of each frame respectively must be separately considered, and these being compounded their resultant is the total force acting on the given bar. Unless stayed, the frames, figs. 26, 27, and 28, are not stable in a plane at right angles to the plane of their lines of resistance.

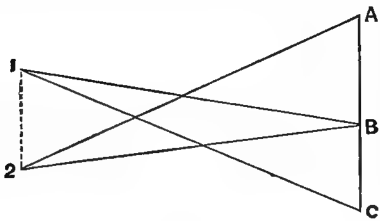


Fig. 29.

156. If an open polygonal frame be subjected to a system of forces applied at its joints which are balanced when the frame is

erect, this system will be also balanced if the frame be exactly inverted, but the struts will become ties, and the equilibrium of the frame will become stable; when inverted the bars may be replaced by ropes, hence the inverted frame is termed a *funicular polygon*. If the joints be conceived to be so numerous that the rope or chain forms a continuous curve, and if the load be merely that due to the weight of the rope, and this be of uniform section and material, then the curve formed is termed the catenary; when qualified the term catenary is applicable to the curves formed by chains loaded otherwise than uniformly. The funicular polygon is simply a particular case of an open polygonal frame; the diagrams and formulæ already given are applicable to its solution. The case of a funicular polygon is presented by several angle poles resisting the strain of a line wire or wires—*e. g.*, let A, B, C, D, fig. 30, represent four angle posts resisting the horizontal strain of the lines passing round them; the wire being equilibriated, the tension on it is the same throughout, hence the horizontal force is the same in each segment. To find the horizontal load on each of the angle posts, from any point draw lines 1, 2, 3, 4, and 5 parallel to the segments of wire respectively, the lines 1 2, 2 3, &c., will represent both in direction and amount the force acting on the post between the segments of wire to which the lines $x1$ and $x2$, $x2$ and $x3$, &c., are respectively parallel. The horizontal load on the wire may similarly be found from the loads on the angle poles, and the trigonometrical formulæ already given are applicable; two forces equal and opposite to the tension on the end segments are necessary to equilibrium of the system, these are furnished by the tension on the line wire on each side of the system. It should be remarked that the horizontal component strain on the posts is alone referred to. The horizontal force acting on the post is on each side of the post sensibly equal to the tension of the wire, and the resultant bisects the angle made by the wire at the post. If the tension be equal on each side of an angle pole for each wire passing round it, the horizontal resultant bisects the angle a formed by the wire; hence the value of this resultant is found by multiplying the tension on the wire by $\dfrac{\sin a}{\sin \frac{a}{2}}$. The following table gives the rela-

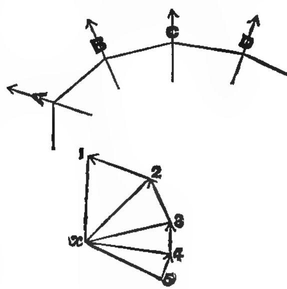


Fig. 30.

tion between the tension of the wire and the resultant tending to pull over the angle pole—*i. e.*, the horizontal load on an angle pole for any angle in the table, is found by multiplying the tension of the wire or wires by the number in the table opposite the given angle:—

Angle.	Relation between Tension of Wires and Resultant.	Angle.	Relation between Tension of Wires and Resultant.
180°	0·00	80°	1·53
170°	0·17	70°	1·63
160°	0·34	60°	1·73
150°	0·51	50°	1·81
140°	0·68	40°	1·87
130°	0·84	30°	1·93
120°	1·00	20°	1·96
110°	1·14	10°	1·99
100°	1·28	0°	2·00
90°	1·41		

157. Poles supporting a straight line are subject only to the vertical pressure due to the weight of the wire; it is only necessary to consider the transverse strength of such poles when the wire is fastened to them, so that breakage of a wire on one side would leave the tension of the same wire on the opposite side unbalanced, and to consider the effects of wind, &c. In the case of a succession of angle poles it is necessary to consider the maximum distance between the poles their strength will admit of. If the poles are erected on a regular curve of given radius, the maximum distance x admissible between them is directly as the radius r, and as the strength of the posts s; and inversely as the force acting on the post on each side T—*i.e.*, the tension of the wire if single, and the resultant of the tensions if multiple. Algebraically: $x = \frac{rs}{\mathrm{T}}$; the powers of resistance of the poles being inversely as the height of the point of application of the force above the setting of the pole, or the length of the pole regarded as a cantilever.

158. The principles explained above, and in Chapter II., may be readily applied to the cases of telegraph poles, whether single, coupled, stayed, tied, strutted, or trussed; and a simple frame, such as those used to support lines, may be designed to resist a

given amount and distribution of load, in the most economical manner, and the stresses in every part of such an actual structure may be found, the details of the load being given. For example, a tied angle pole, if the tie be attached to the post at the point of resultant of the strain, presents the case of a two-bar frame composed of a tie and a strut; its load is the resultant of the tension of the wires, and the stresses may be calculated as explained in Paragraph 151. If an angle post be tied or strutted by a tie or strut applied above or below the point of application of the resultant load, the case is that of a single bar acted upon by three forces; the moment of the load may be calculated as explained for beams, its effective component at right angles to the pole's length being alone considered in calculating this moment, which is the moment of the load with reference to the point of application of the tie or strut. Let fig. 31 represent a tied pole, the load A the angle between its line of action and the pole, and the angle between the tie and pole being known,

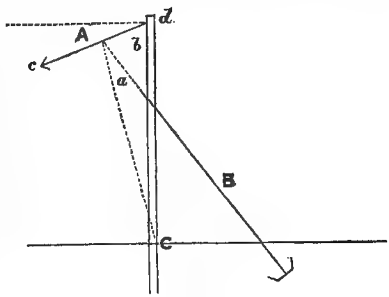


Fig. 31.

it is required to find the stress on the post, on the tie, &c. The case being that of three forces in equilibrio, continue B to meet A, take a point in or below the ground line to represent a centre of resistance, join this point and the point of intersection of A and B; the direction of the tie represents the direction of its stress, the direction CA represents the direction of the resultant through the point C. The forces being in equilibrio must evidently be in the same plane, their lines of action must intersect in one point (Paragraph 6), and they may be represented by the sides of a triangle t, l, e, fig. 32, drawn parallel to them in direction and proportionate to them in length. Algebraically:—

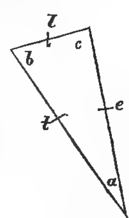


Fig. 32.

$$t : l : e :: \sin c : \sin a : \sin b.$$

From the above formula may be ascertained the load on the tie, which is evidently greater the greater the value of sin c. The longitudinal load on the post is equal to the sum of the vertical components of the forces l and t, found by multiplying l and t by the cosines of the angles between their directions

and that of the axis of the post. The horizontal force through C, which is resisted by the resistance of the earth, is the product of e, and the cosine of the angle between its direction and that of a horizontal line. The greatest bending moment is at the point where the tie is joined to the post. The moment of the load is the product of l, and the distance between its point of application and the point of application of the tie. In fact, the three forces and their directions being found, all other particulars may be found by compounding and resolving these forces. The same may be applied to the case of a strutted pole by altering the position of B, and considering it as a strut. It should be remarked, that ties are preferred to struts for the following reasons: the equilibrium of the tie is stable, that of the strut unstable; although the tie and strut equally strain the pole longitudinally, the former tends to press it into the ground, and hence increases its stability, while the latter tends to lift it from the ground, thereby decreasing its stability; in both cases there is a loss of strength, but it is less injurious in the case of a tie than in that of a strut. The tied or strutted pole should be regarded as a beam; in fastening the tie or strut the fastenings should be inserted in the part of the post which is compressed when the post is strained. The effect of the tie or strut is to shorten the pole considered as a cantilever, and proportionately increase its strength; but if the point of attachment can be placed above the load, the pole is transformed from the condition of a cantilever to that of a beam supported at both ends, hence the advantage of staying or strutting a post above the load rather than below it. If the stay or strut be applied to the same point in the post as the resultant of the transverse load, the case is that of a frame of two bars, and the great advantage of this arrangement over those described above, consists in the fact that the post is a strut merely, it suffers no transverse stress, the horizontal component of the load being balanced by the horizontal component of the stress on the stay or strut; in fact, the bending moment of the load on the post becomes 0.

159. From the above examples the manner of applying the principles stated will be apparent. A trussed post may be considered as a frame of four bars braced; coupled posts may be regarded as frames, or built beams, according to the design, &c. In the example given, fig. 31, one centre of resistance is fixed at the ground line; this is true only when the post is fixed in masonry or brickwork, or by other similar means; when placed directly in the earth this centre is below the surface, and it is manifest in a trussed post not also stayed, tied, or strutted, that the greatest bending moment is at or near the ground line;

hence the post should, if possible, be trussed in such a manner that its greatest moment of resistance should be at the same place. The following illustrates the application of the preceding principles to the case of a trussed post; as a rule the system of trussing is very simple, the commonest case is that in which a tie extends from one end of the post to the other, and a strut brace is inserted between the tie and the post. Let AB, fig. 33,

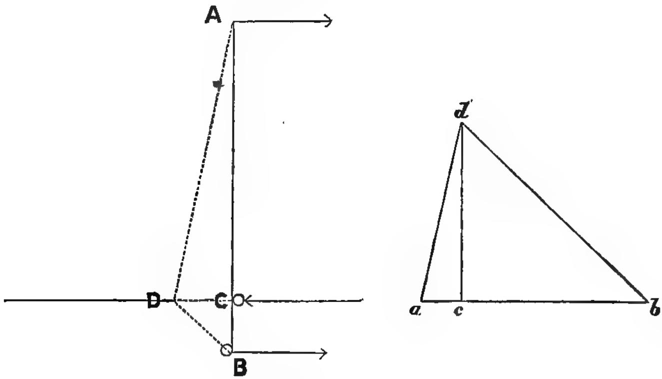


Fig. 33.

represent a post which it is desired to truss; by reason of the moment of the load A, with reference to the point C, being great, the pressure of the post on the ground must be distributed by means of stone or timber placed at C and B. The post is acted upon by three forces, A, C, and B; the bending moment is greatest at C; A and B are together equal to C in magnitude, inversely as their distances from C respectively, and the lines of action of the forces are parallel to each other. It is required to design a truss in which the stress on the post AB, shall be as small as possible compared with that on the other bars of the frame—*i.e.*, in which the maximum assistance shall be given to the post. Draw the line *ab* to represent the force C and the sum of the forces A and B; divide it at *c*, that *cb* may represent the force B, and *ac* the force A; this line is the diagram of forces. From *c* draw *cd* parallel to AB, and of a length compared with the line *ab*, to represent the stress to be permitted on the post AB on each side of the strut brace, draw *ad* and *bd*, and the figure represents the diagram of stresses. Draw AD and DB parallel to *ad* and *bd* respectively, and join DC by a line which will be parallel to *ab*; ADB represents the trussed pole,

CD the length and position of the strut brace which must be applied in order that the stresses on AC and CB may not exceed *dc*. The diagram *adb* represents the stresses; each line represents the stress on the bar to which it is parallel; but as AB is divided into two parts by a centre of resistance at C, the line *dc* represents *each* of the equal and opposite pressures acting along AC and CB respectively, AC CB being regarded as two bars suffering equal pressures. It is evident the less the stress *dc* admissible on the pole, the longer must be the strut brace DC; and if the stress *dc* be supposed infinitely small, the strut brace will be infinitely long—*i.e.*, if the ties AD, DB be parallel, the load on the pole vanishes. By means of the method illustrated, a truss can be designed; when the stress on the pole is fixed, the length of the necessary strut brace may be deduced, and with a given length of strut brace, the stresses may be deduced (Paragraphs 153, &c.) On examination of figure 33 it will be seen the strut brace is applied where the bending moment is greatest; and it will be apparent, if the case presented be examined geometrically, that for any given movement of the end A in the direction of the load, the elongation of the tie necessary to permit of such movement must be less the higher the strut brace is removed above C; in other words, if the strut brace be removed to any point above C, its efficacy both to prevent bending of the post, and to render available the tensile strength of the tie to prevent motion at A, is diminished. The position of maximum efficiency of the strut brace is at C; but, although by placing it higher its efficiency is reduced, in practice the conditions which render tying or strutting impracticable, frequently render it necessary to place the strut brace in the trussed pole higher than its position of maximum efficiency; but when this position cannot be attained it should be approached as nearly as practicable. The strut brace in poles trussed, as in fig. 33, is often placed midway between the ground line and the point of resistance at A; as explained above, there is a needless sacrifice of efficiency in placing it so high. It should be remarked that by bending the pole slightly by means of the tie and brace, the combination is rendered stiffer. As in telegraph construction, the mode of distribution of the load does not vary, a frame can be readily designed in which the maximum strength and stiffness is attained with the minimum expenditure of materials; and the requirements of the case being so simple, departure from correct principles is the less excusable. In the case represented in fig. 33, the forces are represented as parallel, and in most cases this parallelism may be assumed without sensible error; if, however, the dip of the wire at A be great, the effective component of the

force A in the horizontal direction should be taken instead of the force A, and the vertical component of the load must be added to the stress *dc*.

SECTION II.—*Stability of Earth.*

160. A mass of earth gives way by the sliding of its parts on each other. In earth commonly so called this tendency to slide is resisted by the friction between the grains and their mutual adhesion; in solid rock, when a load tends to produce this sliding, it is resisted by the stress of the material. If there were no stability due to friction between the grains, a mass of loose earth could not be heaped up, it would act like a fluid; this is the case presented by soft mud, in which the stability of friction is destroyed by the presence of water. But in dry earth and earth not containing water in excess, there is friction between the grains; this friction causes the sides of a heap of loose earth to assume a particular slope, termed the *natural slope*, the inclination of which depends on the co-efficient of friction of the particular material. The angle of inclination of the natural slope to the horizon is termed the angle of repose for the particular material; it is that angle the tangent of which is the co-efficient of friction (Paragraphs 43, 44, 49).

161. The stability of friction is sufficient to maintain this uniform slope, and is relied on to give permanent stability to the sides of cuttings and embankments; the adhesion of earth being usually rapidly destroyed by exposure to the weather, is relied upon only for temporary purposes, as to maintain the vertical sides of a hole or cutting during excavation. In general, in order to economise land and reduce the surface of the bank exposed to the weather, embankments of earth have a somewhat steeper slope than the angle of repose; a dressing of dry stones, or a covering of grass, is then relied on to prevent sliding: these act by protecting the earth more or less from the action of the weather, while the stones by their weight, and the grass by the holding action of its roots, supply any additional stability required to prevent slipping. If a bank be made of loose earth the angle of repose cannot be exceeded, because the earth, being loose, assumes this slope when heaped together. It is when the slope has to be cut in the undisturbed earth the adhesion is available to render a steeper than the natural slope possible; and it is then that such expedients as those mentioned above are employed to partially preserve the adhesion, and supply its defect.

162. The consequences of the frictional stability of earth are very important, the following are illustrative examples:—A

structure supported on loose earth cannot be regarded as supported on a prismatic column of earth, the frictional stability of the earth causes the weight to be distributed over a greater area in each successively lower cross-section, and the supporting column is hence a frustrum of a cone or pyramid, of which the base of the structure forms the smaller end. If a post attached to a base plate buried in the ground be pulled up perpendicularly, provided the base plate do not separate from the post, the mass of earth disturbed is not a prism but a frustrum of a cone or pyramid; its smaller end is equal and similar to the base plate, its larger end is at the surface of the earth, its axis is equal to the original depth of the plate, and the inclination of its sides is equal to the angle of repose of the earth. The frictional stability of earth acts in the same manner on a post without a base plate to prevent the post being torn up by a transverse load. In ramming loose earth, each blow given by the rammer acts effectively only through a thin stratum; for by reason of the frictional stability of the earth, the force of the blow is distributed over an area rapidly increasing with the depth, and at an inconsiderable depth the intensity of the blow is so small as to be ineffective for the purpose required; hence, earth cannot be consolidated in layers exceeding 9″ or 1 foot by ramming in the usual manner. Other important consequences of the frictional stability of earth are noticed in the sections on earthwork and foundations. The firmness of a pole in the ground is in a great measure also due to adhesion of the earth; hence, after the earth has become consolidated, the post is much firmer than when the earth is loose.

Section III.—*Stability of Blockwork.*

163. The stability of blockwork structures, as masonry and brickwork, is due to two causes—viz., *friction* and *position;* and such structures may fail either by the blocks sliding on each other, or by the overturning of one block on another at the joints.

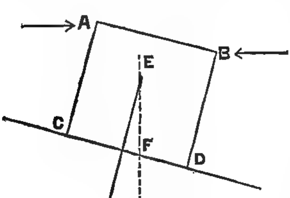


Fig. 34.

In fig. 34, let ABCD represent the upper block, and DC a plane joint; the pressure on the joint is a distributed force, let EF be the direction of its resultant; the point F in which this line meets the surface of the joint is termed the centre of pressure, or centre of resistance of the joint. It is essential to stability—1. That the obliquity of the pressure do not exceed the angle of repose—*i.e.*, that the block ABCD have stability of friction; for if this condition

be not fulfilled, the upper block will slide on the lower. 2. The following ratio must not exceed a certain fraction—the distance between the centre of pressure and centre of figure divided by the diameter of the joint measured through those points; if this fraction be exceeded, then the upper block is in danger of turning over. When the second condition is fulfilled, the block ABCD is said to have *stability of position.* The value of the above ratio varies in practice between one-eighth and three-eighths, being varied with the purpose of the structure; thus, a greater value is allowed in retaining walls than in abutments: in the the former class of structures it varies between ·3 and ·25; in the latter, to avoid tension at any point in the joint, it is restricted according to the figure of the joint, it is one-sixth in the common case of rectangular structures.

164. The moment of stability in a given vertical plane of a body or structure supported at a plane joint, is the moment of a couple, which must be applied in the given plane in addition to the weight of the structure, to transfer the centre of resistance of the joint to the extreme point consistent with stability of position; it is equal to the product of the weight of the body, by the horziontal distance between a vertical line drawn through its centre of gravity and the limiting position of the centre of resistance of the joint. The couple is composed of any force tending to overturn the structure, and the equal and parallel resistance of the joint. The moment of stability M, is expressed algebraically as follows:—Let w represent the weight of the body or structure above the given joint, dq the distance of the limiting position, and dr the actual distance of the centre of resistance from the centre of figure of the joint; d being the diameter of the joint measured through the centres of figure and resistance, q and r being the fractions of the diameter between these centres and the centre of figure respectively. If fig. 34 represent a structure or block on a joint at CD, it is evident if a force A tend to overturn the block, the stability is less than that with respect to a force acting at B; for in one case the actual deviation of the centre of resistance from the centre of figure is in the same direction as the limiting deviation, while in the second case it is in the opposite direction. As d is measured on an inclined line, it is necessary to reduce it to horizontal distance; to do this it must be multiplied by the cosine of the angle of inclination of the joint to the horizon; hence the moment of stability is—

$$\mathrm{M} = w\ (q \pm r)\ d \text{ cosine } k;$$

in which k is the angle of inclination of the joint to the horizon,

and the top or bottom sign in the brackets is to be taken according as *qd* and *rd* are in opposite or the same direction, measured from the centre of figure of the joint. It is assumed in the above that the block ABCD will act as one piece, and not separate at its joints, and the resistance of the mortar or cement interposed at the joint CD offers no appreciable resistance. The above formula is evidently applicable to the case of a wall or other structure constructed on a horizontal plane, it being merely necessary in this case to omit the factor *cosine k*.

165. If a structure be composed of a series of blocks (or of a series of layers so connected that each layer acts as one block) connected by plane joints, the two conditions of stability must be fulfilled at each joint, and the formula given above is applicable in the case of each joint. The resultant pressure at any joint is the resultant of all the forces which act on one of the parts into which the structure is divided by the joint; and the point where the line of action of this resultant cuts the plane of the joint is the centre of pressure. If fig. 35 represent a series of blocks forming part of a structure, and the arrow C_1 be the direction of the resultant of the forces acting on the highest block—*i.e.*, its gross load, the point where this resultant meets the joint 1, is the centre of pressure of that joint. If this resultant be combined with the resultant of the forces acting on block 1 1 2 2 directly, then the resultant of all the forces acting on the next joint is obtained, and the point where this meets the second joint C_2, is the centre of pressure of that joint. The dotted line RR, in the figure, traversing the centres of pressure, is termed *the line of resistance.* The straight lines representing the successive resultants may be in one line, parallel to each other, or they may intersect in one point, or in a series of points as in the figure; in the last case a curved line PP, touching all the sides of the polygon so formed, is termed *the line of pressures.* The properties of these curves relative to the two conditions of stability, which must be fulfilled for each joint, are as follows:—It is essential to stability of position that the line of resistance do not deviate from the centre of figure by more than a certain fraction of the diameter of the joint, measured in the direction of the deviation; it is essential to stability of friction that a tangent to the line of pressures through the centre of pressure make an angle with the normal to the joint less than the angle of repose. The most

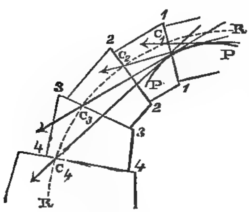


Fig. 35.

advantageous direction for pressure in an arch or other block-work structure is attained when the resultant direction of the pressure on each joint is perpendicular to the plane of the joint. In every case the term resultant used above is applied to the resultant of the gross load—*i.e*, the external load and the weight of the material of the structure itself.

166. In telegraph structures the application of the above principles is usually confined to simple cases, but these are of frequent occurrence. Wooden or iron posts are often erected on stone or brick plinths, or attached to walls; wires are attached to walls, chimney stacks, and similar structures; stone pillars are sometimes used to support lines where stone is procurable on the spot; and the principles explained are applicable to any structure which depends more or less for its stability on its weight and the size of its base, irrespective of its form and the material of which it may be composed. It should be remarked, in a structure depending for its stability on its weight and the size of its base, the lower its centre of gravity the more this point will be raised by any given movement of the structure, and the greater the displacement of the structure necessary to bring the centre of pressure to its limiting position—*i.e.*, the lower the centre of gravity the greater the stability of the structure.

SECTION IV.—*The Catenary.*

167. A chain or cord of uniform section and material, loaded with its own weight only, suspended between two fixed points, hangs in a curved line, termed significantly the catenary or chain curve. When the term catenary is qualified, it may refer to the curve formed by a chain loaded in any other manner, but in telegraph practice the wires or cables are only loaded with their own weight. The direction of the stress on the cord at any point is that of a tangent to the curve at that point. The load may be resolved at each point but the lowest into two rectangular components, one vertical and equal to the weight of the chain at that point, the other horizontal and representing the horizontal tension. At the lowest point the curve is horizontal, and the load is equal to the horizontal tension only; as the vertical component vanishes at this point, the load on the chain here is less than at any other point in the curve. If ABC, fig. 36, represent the curve, the point B, where it is horizontal, is termed its vertex; DE is a horizontal line, the line BF drawn to the vertex is termed the *modulus* or *parameter* of the catenary, and on this line depends the other dimensions of the curve. If

any ordinate GK $= x$, its abscissa or horizontal distance from

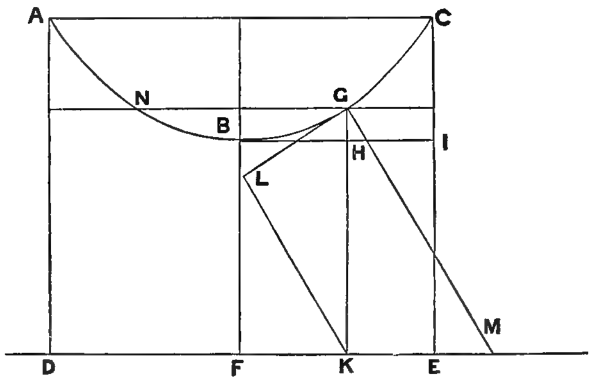


Fig. 36.

F = FK $= y$, and the length of the modulus FB $= m$, then the length of the ordinate is given by the equation—

$$x = \frac{m}{2}\left(e^{\frac{y}{m}} + e^{-\frac{y}{m}}\right), \quad \text{..................(1.)}$$

in which e = the base of Napierian logarithms; or, using a table of common logarithms, $e^{\pm\frac{y}{m}} = 10^{\pm \cdot 4343\frac{y}{m}}$ nearly. The abscissa in terms of the ordinate—

$$y = m \text{ hyp. log. } \left(\frac{x}{m} + \sqrt{\frac{x^2}{m^2} - 1}\right). \quad \text{........(2.)}$$

The length of the arc—

$$\text{BG} = v = \frac{m}{2}\left(e^{\frac{y}{m}} - e^{-\frac{y}{m}}\right) = \sqrt{x^2 - m^2}. \quad \text{......(3.)}$$

If a right-angled triangle be constructed with GK as hypotheneuse, GKL; then KL will equal the modulus BF, LG will be a tangent to the curve at the point G, and a line drawn through G at right angles to GL, meeting the horizontal line in M, is equal to the radius of curvature at G.

168. The mechanical properties of the curve are as follows :— The horizontal tension at the lowest point B—*i.e.*, the total load at this point—is equal to the weight of a length of the wire or chain equal in length to the parameter BF; or if ϖ be the weight

of a unit length of the wire, as 1 foot or 1 yard, the tension at the lowest point $T = \pi m$, the modulus $m = \frac{T}{\pi}$, and the tension at any other point $G = T^1 = \pi x$; $T^1 = T + \pi \times d$; or the tension at any point G exceeds that at any lower point A, by a force equal to the weight of a piece of the wire equal to the difference of level, $GH = d$. Thus in any span of wire the tension at either point of suspension exceeds that at the lowest point by an amount equal to the weight of a length of the wire equal to the dip below the point of suspension. The vertical load between any two points in the curve, or rather the vertical component of the load, is evidently the weight of the wire between these points $= \pi v$; therefore the tension on the wire at any point $T^1 = \sqrt{T^2 + (\pi v)^2}$; or the square root of the sum of the squares, of the weight of a piece of the wire equal in length to the parameter, and of a piece BG equal in length to the arc between the vertex and the point taken.

169. The above formulæ may be applied to the case of a telegraph wire or cable to calculate such particulars of form, distribution of load, &c., as may be required in practice. Let ABC, fig. 36, represent a span of telegraph wire suspended at the points A and C in the same horizontal line, or a span suspended at the points A and G not in the same horizontal line; let a denote the span DE, substituting an infinite converging series for the finite equation (1.)—

$$x = m\left(1 + \frac{y^2}{2m^2} + \frac{y^4}{2\cdot3\cdot4m^4} + \text{\&c.}\right) \dots\dots\dots\dots\dots (4.)$$

substituting for m its value $\frac{T}{\pi}$, and performing the multiplication—

$$x = \frac{T}{\pi} + \frac{y^2\pi}{2T} + \frac{y^4\pi^3}{2\cdot3\cdot4T^3} + \text{\&c.} \dots\dots\dots\dots\dots\dots (5.)$$

By means of this formula the height of any ordinate may be calculated—*i.e.*, the height of the wire at any point G. The dip being the difference of height, $d = GH$, may be found for any abscissa FK, by subtracting from x the modulus $= \frac{T}{\pi}$; hence the dip of the vertex below any point in the span is—

$$d = \frac{y^2\pi}{2T} + \frac{y^4\pi^3}{2\cdot3\cdot4T^3} + \text{\&c.} \dots\dots\dots\dots\dots\dots\dots\dots (6.)$$

If the supports be on the same level, and it be required to find the dip, in this case $y=\frac{a}{2}$; substituting this value in (6)—

$$d=\frac{a^2\pi}{8T}+\frac{a^4\pi^3}{384T^3}+\&c.\dots\dots\dots\dots\dots(7.)$$

By means of the above formulæ the dip may be calculated with any requisite degree of accuracy, the points of suspension being in the same horizontal line, or differing in height; and the depression of the wire at any horizontal distance from either point of support may also be ascertained. The tension at any point may be calculated from the difference of level between the point taken and the vertex; the difference between the tension at the vertex and at any higher point is $T^1-T=\pi d$...(8). In applying (7) to spans not exceeding 200 yards under the ordinary conditions of working load = one-fourth ultimate load, the first term only is generally sufficient for practical purposes; from which it would appear that the dip varies approximately directly as the square of the span and the weight of the wire per unit of length, and inversely as the tension.

170. The tension at either point of suspension is $T_2=T+\pi d$; as T_2 is increased, d decreases, and T increases and *vice versâ*—*i.e.*, as d is decreased, the horizontal component of the tension is increased, and its vertical component decreased. Thus there is a value of d for which the tension at each point, including the points of suspension, is a minimum. This will be apparent if it be considered as the dip is increased, although the tension at the lowest point of the span is diminished, that at the points of suspension may be increased by reason of the greater weight due to the greater length of wire. If the points of suspension be in the same horizontal line, this minimum tension is attained when m the modulus $=\frac{a}{2\cdot4}$, and the length of the ordinate AD or $CE=\frac{3}{4}a$, the difference in level or the dip $d=a\left(\frac{3}{4}-\frac{1}{2\cdot4}\right)=\frac{a}{3}$; or the minimum tension on the points of support and on the wire is attained when the dip is equal to one-third of the span. With this relative dip $m=\frac{T}{\pi}=\frac{a}{2\cdot4}$; $\therefore T=\frac{a\pi}{2\cdot4}$, the tension at the lowest point; and $T_2=\frac{3a\pi}{4}$...(9), the tension at the points of suspension or highest points; the ratio of the tension at the vertex to that at either of the points of suspension is 10 : 17. By means of

these formulæ may be found the longest span possible with wire of a given material, for (9) this span $=\frac{4}{3} \times \frac{s}{\varpi}$; in which $s=$ the ultimate strength of the wire, or $\frac{s}{\varpi}=$ the modulus of tenacity of the material, and is a constant quantity for the same material. For example, a material having a tenacity of 30 tons per square inch, 1 cubic foot of which weighs 481 lbs., $\frac{s}{\varpi} = 3{\cdot}81$ miles; if 4 be assumed as factor of safety, the greatest practicable span with wire of such material $= \frac{4 \times 3{\cdot}81}{3 \times 4} = \frac{3{\cdot}81}{3} = 1{\cdot}27$ mile. In such calculations it is easier generally to use the constant proportion or modulus of tenacity, but the same result may be obtained for a particular sized wire—*e.g.*, iron wire, No. 7 B.W.G., weighing 4 cwts. per mile, ultimate load 15·25 cwts., then $s = 15{\cdot}25$, $\varpi = 4$; thus, $a = \frac{4 \times 15{\cdot}25}{3 \times 4} = 5{\cdot}083$, which divided by 4 as factor of safety $= 1{\cdot}27$ mile, as above.

171. The formula is applied in the above example to wire suspended in air; if the wire be suspended in water, it is necessary to allow for loss of weight equal to that of the water displaced, by assigning a different value to ϖ; thus, iron, spec. grav. 7·7, immersed in water would lose $\frac{10}{77}$ of its weight; or the span in water would exceed that in air as 7·7 to 6·7—the heaviness of air being but $\frac{1}{773}$ that of water is neglected. The actual length of wire may be calculated from the equation for the arc; substituting an infinite series for the finite equation (3), the length of the arc between the vertex and any higher point G is—

$$v = y\left(1 + \frac{y^2}{2{\cdot}3{\cdot}m^2} + \frac{4}{2{\cdot}3{\cdot}4{\cdot}5m^4} + \text{\&c.}\right) \qquad (10.)$$

Substituting $\frac{\mathrm{T}}{\varpi}$ for m—

$$v = y\left(1 + \frac{y^2\varpi^2}{2{\cdot}3{\cdot}\mathrm{T}^2} + \frac{y^4\varpi^4}{2{\cdot}3{\cdot}4{\cdot}5\mathrm{T}^4} + \text{\&c.}\right) \qquad (11.)$$

from which v may be calculated with any requisite degree of accuracy for any point in the curve. If the points of suspension are not on the same level, then the length of the whole arc is obtained by calculating the length between the vertex and each point of suspension separately; the sum of the two quantities so

obtained is the whole length of the wire between the points of suspension. If the points of suspension be on the same level, $y = \frac{a}{2}$; or the vertex is in the middle of the span. Substituting in this case for y its value $\frac{a}{2}$, the length of the arc between the vertex and either point of suspension multiplied by 2 is the whole length of wire between the points of suspension $= 2\,v_1$—

$$v_1 = \frac{a}{2}\left(1 + \frac{a^2\pi^2}{2 \cdot 3 \cdot 2^2 \cdot T^2} + \frac{a^4\pi^4}{2 \cdot 3 \cdot 4 \cdot 5 \cdot 2^4 T^4} + \&c.,\right.$$

$$2v_1 = a + \frac{a^3\pi^2}{24T^2} + \frac{a^5\pi^4}{1920T^4} + \&c. \ldots\ldots\ldots\ldots (12.)$$

When the dip is small the first two terms are sufficiently accurate for practical purposes.

172. By means of (12) may be calculated the effect of the elasticity of the wire and changes of temperature on the tension and dip, calculations only of practical importance when the dip and span are small. If λ be the co-efficient of elasticity of the wire, and v_1 the length of the arc, under a tension of t pounds v_1 will become—

$$v_2 = v_1\,(1 + \lambda\, t); \ldots\ldots\ldots\ldots\ldots\ldots\ldots (13.)$$

By substituting $2v_2$ for $2v_1$, in (12), the effect of the lengthening on the tension T may be ascertained for a wire suspended between two points on the same level. If the points of suspension be not on the same level, then (11) must be applied, and the calculation performed for each side of the curve. It should be remarked that the first two terms are, as a rule, sufficient in practice; as the tension at the ends differs from that at the vertex, the tension t is the mean tension, and the maximum tension must be less than the proof load.

173. The effect of change of temperature on the wire is to alter its length, and alter consequently the tension and dip; if θ be the co-efficient of expansion for each degree of elevation of temperature, for a difference of $\pm$K degrees, the length of the arc will change from v to $v(1 \pm \theta K)$, the upper or lower sign being used accordingly as the temperature is raised or lowered; but as the change of temperature causes a change of tension under which the length v is altered by reason of the elasticity of the material, the ultimate effect of a change of temperature on the length of the arc is the difference between the expansion or contraction due to change of temperature, and the consequent

contraction or expansion due to change of tension from T to T_1; hence, the alteration of length due to a difference of temperature $= \pm K$, is from v to $v(1 \pm \theta K)\{\mp \lambda(T^1 - T)\}$. If the points of suspension be on the same level, v_1 being the length of the arc on each side of the vertex, then, previous to the change of temperature—

$$2v_1 = a + \frac{a^3\pi^2}{24T^2}; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(A.)}$$

after the change of temperature—

$$2v_1(1 \pm \theta K)\{1 \mp \lambda(T^1 - T)\} = a + \frac{a^3\pi^2}{24T_1^2}. \quad \ldots\ldots\ldots \text{(B.)}$$

If A be subtracted from B, $2v_1$ be assumed $= a$, the term containing λ and θ as factors be neglected, and every term be divided by a, then—

$$\pm \theta K \mp \lambda(T_1 - T) = \frac{a^2\pi^2}{24}\left(\frac{1}{T^2} - \frac{1}{T_1^2}\right). \quad \ldots\ldots\ldots \text{(14.)}$$

By putting for T_1 its values (7) $\frac{a^2\pi}{8d}$ and $\frac{a^2\pi}{8d_1}$, the variation in the dip is obtained. The above equation should be applied by trying the value of T_1 or d respectively, which will satisfy it.

174. If the points of suspension are not on the same level, but one be at G and the other at A, then the portion of the curve below the horizontal line NG drawn through the lower point of suspension is symmetrical about the line BF, and the vertex B is not in the centre of the span, but nearer to the lower point of suspension. To find the horizontal distance of the lowest point or vertex from each point of suspension respectively, the difference of level d_2 being given, the dip below the lowest point of suspension is (6)—

$$d = \frac{y^2\pi}{2T}, \quad \ldots\ldots\ldots\ldots\ldots \text{(C.)}$$

below the highest point—

$$d_1 = \frac{y_1^2\pi}{2T}; \quad \ldots\ldots\ldots\ldots \text{(D.)}$$

the difference of level between the points of suspension $d_2 = d_1 - d = \frac{\pi}{2T}(y_1^2 - y^2)$; putting $\frac{a}{2} + x$ for y_1, and $\frac{a}{2} - x$ for y, $d_2 = \frac{a\pi}{T}x$, or $x = \frac{d_2 T}{a\pi} \ldots$(15); the distance from the lower point of suspension is

$\frac{a}{2}-\frac{d_2\mathrm{T}}{a\pi}$, and from the higher point $\frac{a}{2}+\frac{d_2\mathrm{T}}{a\pi}$. As only the first term of the series (6) is taken, this formula is only applicable to spans up to about 200 yards under ordinary conditions as to tension. If more terms of (6) be used, the formula is applicable to longer spans, and under other conditions as to tension. Thus, if two terms of the series (6) be taken then—

$$d_2=\left(\frac{\pi a}{\mathrm{T}}+\frac{\pi^3 a^3}{24\mathrm{T}^3}\right)x+\left(\frac{\pi^3 a}{24\mathrm{T}^3}\right)x^3;$$

and by substituting numerical trial values, the value of x may be obtained with sufficient accuracy for all practical purposes.

175. A ready mode of noting differences of level of the wire is to have the curve drawn to scale, and apply it to a drawing of the profile of the ground and the objects the wire is to pass over; the curves may be calculated by means of the series for the ordinate with sufficient accuracy for any purpose occurring in practice. The curves might be cut in sheet brass, and the values of the scales marked on the brass. A drawing of the catenary is given in M. Blavier's "Telegraphie Electrique" for use as described above, but the scales given with the curve do not agree. Many of the above formulæ are contained in M. Blavier's work; they are not all deduced in so simple a manner as above, and the series representing the length of the arc, and the formulæ for the influence of temperature on the tension, &c., given by M. Blavier, are inaccurate.

176. When the difference of level between the points of suspension is very great, the curve formed by the wire may be only half the curve ABC, fig. 36; in this case one point of suspension is at the vertex, and the dip is equal to the difference in level; in this case (6) $d=\frac{a^2\pi}{2\mathrm{T}}$, or the distance of the supports is $\sqrt{\frac{2d\mathrm{T}}{\pi}}=a$. This is to be avoided in practice; and in doubtful cases either this formula should be applied to find the minimum distance admissible between posts greatly differing in height, or the distance should be found as follows:—It being decided to give the wire a certain dip d, below the lower point of suspension, then approximately (C) and (D) $-y=\sqrt{\frac{2d\mathrm{T}}{\pi}}$, and $y_1=\sqrt{\frac{2d_1\mathrm{T}}{\pi}}$; from which y and y having been found, the distance $y+y_1$ is the distance the points of suspension must be placed apart to allow a dip $=d$ below the lower point.

177. If a chain be loaded uniformly along a horizontal line—*i. e.*, the load on any length, as BG, is proportionate to the hori-

zontal line FK, then the chain hangs in a curve, termed a parabola. In the calculations for finding particulars of form, &c., of bridge chains, the formulæ of the parabola are commonly employed instead of those of the catenary; in telegraph construction the equations of the parabola are also frequently employed; but the parabola and catenary are only nearly alike near the vertex; and hence, when the dip and span are considerable, the curve cannot be considered as approximating to the parabola. The case of a suspension-bridge chain differs from that of a telegraph wire in two important particulars: it assists in supporting a load (the bridge platform, &c.), which is distributed almost uniformly over a horizontal line, and the spans to which the formulæ are applied are much shorter than those to which the formulæ are required to be applicable in the case of a telegraph wire. As in telegraph construction, the calculations need only be made once, by reason of the uniformity in conditions but few different calculations are required, and when really necessary accuracy is frequently of great importance—it is preferable to consider the curve as a catenary. The formulæ given above are simple enough for general use, if merely approximate results be desired; a higher degree of accuracy is attainable at will.

SECTION V.—*Stability, Motion, and Friction in Fluids.*

178. A perfect fluid is defined as a body which has no tendency to preserve a definite shape; the definition therefore includes gases as well as liquids. The only fluids which it is necessary to consider in practice are air and water, seldom the former. The property of fluidity which distinguishes liquids from solids (although it does not hinder them from obeying the ordinary laws of statics), introduces other considerations which constitute the equilibrium of fluids into a distinct branch of statics, termed *hydrostatics.* The fundamental principle of hydrostatics is as follows:—All fluid pressure between two fluid surfaces, or between a fluid and a solid, is normal to the surfaces in contact, and of equal intensity for all positions of these surfaces—*i. e.*, whether the surfaces be vertical, horizontal, or oblique. From the above principle it follows, the pressure in a fluid at all points at the same level is of equal intensity; whatever the angle at which a plane surface is immersed, or at which the sides of a fluid containing vessel may stand, the pressure is normal to the immersed surface, and its intensity depends on the depth to which it is immersed. The intensity of pressure is greater at the lower of two points than at the higher point, by the intensity of the pressure of a column of liquid equal in height to the

difference in level—*i.e.*, by the weight of such a column per unit of area. The above statements suppose the fluid to be still, and acting by its own weight alone. If the surface of water be exposed to the air, the pressure of the atmosphere must be added to that of the water; but frequently from the equal pressure of the air on all sides, the pressure of the atmosphere may be neglected. It should also be remarked, that as the internal pressure of a fluid acts on the matter of the fluid itself, compresses it and increases its density, the density is thereby made to increase with the depth. In fluids which are very compressible, as air, the density varies nearly as the depth; but in the case of water, the increase of density may be neglected in practice. A body immersed in a liquid displaces a volume of the liquid equal to its own volume; the liquid presses on the body with a total pressure equal to the weight of liquid displaced. The resultant of this pressure acts vertically upwards through the centre of gravity of the displaced volume, which point is termed the *centre of buoyancy*. If the weight of the body immersed be greater than this resultant—*i.e.*, the body be specifically heavier than the liquid, the body sinks; if the reverse be the case, the body rises, moving in either case under the action of the difference of the two forces—viz., its own weight and the resultant of the fluid pressure. If a plane surface be immersed in a liquid (it may be the sides of the containing vessel or the surface of an immersed body), the pressure of the liquid on such surface is perpendicular to the surface in direction, and equal in magnitude to the weight of a column of liquid whose transverse area is the area of the immersed surface, and whose height is the depth to which the centre of gravity of that surface is immersed. The position of the point of application of the resultant, or the centre of pressure, depends on the inclination of the immersed surface; if this surface be horizontal, the centre of pressure coincides with its centre of gravity; if it be inclined, the centre of pressure is below its centre of gravity a distance depending on the angle of inclination; in the latter case the pressure is assumed to vary uniformly at each point of the surface, as the distance of such point from the line of intersection of the planes of the immersed surface and of the upper surface of the liquid.

179. A cubic foot of pure water at 62° F. weighs 62·355 lbs.; a cubic foot of sea water weighs about 64·25 lbs. Fresh water has its maximum density at 39°·1, sea water at about 25°·4. In passing from 32° to 212° F., water expands about $\frac{1}{23}$; and at the temperature of maximum density, 1 cubic foot of fresh water weighs 62·425 lbs. A column of pure water at 52°·3 F. 1 foot

high, presses on its base with a force = 62·4 lbs. per square foot, or ·4333 lbs. per square inch; the intensity of the pressure of a column of average sea water = 1·026, that of a similar column of pure water. The above laws and data are applied in designing cable tanks, in calculating the pressure of water on cables and other immersed bodies, and partially immersed structures. A cable suffers the pressure of the water and that of the atmosphere; but the sides of a cable tank containing water, and the bottom of a floating ship, suffer only the pressure of the water, that of the air being neutralised by its equal intensity within and without the vessel. The unit 1 atmosphere refers to a pressure equal in intensity to 29·922 inches of mercury at 32° F., = 2116·4 lbs. per square foot, or 14·7 lbs. per square inch. It is evident the sides of a cable tank are not required to be so strong above as below, and they should therefore increase in strength downwards, to resist the increased pressure due to the increase of depth of fluid.

180. The only particular in which the motion of air is of practical importance is in considering the pressure of the wind on telegraph structures; the maximum intensity of wind pressure observed in Britain is 55 lbs. per square foot on a plane surface at right angles to the direction of the wind. During the last destructive cyclone at Madras the intensity of pressure reached 42 lbs. During the cyclone at Calcutta in 1866, the highest recorded intensity was 33 lbs.; but the instrument had already become bent, and shortly afterwards the instrument, roof, verandahs, &c., were blown away; the intensity was undoubtedly much higher than registered. The maximum intensity of pressure on a cylindrical surface is equal to about half the above quantities respectively per unit of area of the plane projection of such surface.

181. As stated above, a body immersed in a fluid medium, if free to move, ascends and floats or sinks, according to the relation between the specific gravities of the medium and body immersed; the body tends to sink under the influence of its own weight, the effective force with which it is urged is the difference between the fluid pressure and the force of gravity acting on the body. Under these circumstances the body moves with the force of gravity minus the force of gravity $\times \dfrac{\text{spec. grav. medium}}{\text{spec. grav. body}}$; thus, the velocity with which a piece of iron tends to sink in water $= 32 - 32 \times \dfrac{1}{7 \cdot 7} = 27 \cdot 5$—*i.e.*, it would tend to acquire a velocity of 27·5 feet in one second under the accelerating force

due to the combined action of the fluid pressure and its own weight. A fluid medium offers resistance to displacement, for a body moving in a fluid strikes successively different portions of the fluid and impresses motion upon them, losing itself as much motion as it thus communicates; the fluid therefore offers a resistance to the motion of the immersed body. Thus resistance increases as the square of the velocity of the body's motion directly; for the resistance of the medium to the motion of a plane surface moving at right angles to its plane, with any velocity, is equal to the weight of a column of the medium of a transverse section equal in area to the moving surface, and a height equal to that which a body must fall from to acquire its actual velocity; this height being as the square of the velocity, it follows that the resistance of the medium varies as the surface of the body and as the square of its velocity. Hence, a body moving under the combined influence of its own weight and a fluid pressure, moves with a velocity tending to increase by reason of the continued action of the forces; but it tends to increase in an arithmetical ratio with equal increments of time, whereas the resistance of the medium increases as the square of the velocity. Hence, the velocity will increase to a certain maximum, at which it will remain constant, and this constant velocity is attained when the resistance of the medium is equal to the force under which the body moves; for in this case the further action of this force is neutralised by the resistance of the medium, and the body moves with the velocity it has acquired up to this instant without further acceleration. The force with which a piece of cable tends to sink is its weight in water; under the action of this weight alone its velocity tends to increase, but it attains a constant velocity when the resistance of the medium is equal to this weight—*i.e.*, when its weight in water $w = Cv^2$; v being its velocity, and C a quantity depending on its surface.

182. If a body be moved in a liquid, a sensible resistance to its motion is caused by friction between the sides of the body and the liquid, in addition to the resistance to displacement described above. This friction depends in some manner on the nature of the surface, being greater with rough than smooth surfaces; it is sometimes assumed in the case of a cable to vary as the diameter, but in practice it is safer to use a constant or co-efficient of friction ascertained by experiment in each case. The friction is also assumed in practice to vary as the square of the body's motion and the area of its surface.

183. Water moving in an open channel, as a river or canal, does not move with the same velocity in every part of its transverse section; the particles at the surface in the centre of the stream

move with the maximum velocity, and the water near the banks and the bottom has its motion retarded by friction; that at the bottom has the minimum velocity. In a very slow current the maximum and minimum velocities are to each other about as 1 to 2, while in ordinary cases they are as 3 to 5, and with very rapid currents still more nearly equal. When the velocity of the current in contact with the bed, and nature of the material of the bed, are such that the current has no tendency to wash along the material of the bed, the channel is said to be stable. The maximum velocity of current consistent with stability differs with the material of the bed, and is stated to be as follows:—

Material of Bed.	Velocity of Current per Second.
Soft Clay,	·25 foot.
Fine Sand,	·50 „
Coarse Sand and Gravel,	·70 to 1·00 „
Gravel, 1 inch in diameter,	2·25 feet.
Pebbles, 1½ inch diameter,	3·33 „
Heavy Shingle,	4·00 „
Soft Rock, Brick, Earthenware,	4·50 „
Rock, various kinds,	6·00 „ and upwards.

The above table is given by Professor Rankine on the authority of M. Du Buat, and it is selected by the author because the velocities given are low compared with those given by other authorities. Many rivers, particularly in tropical climates, have both the beds and banks unstable, and such rivers are exceedingly difficult to cross successfully by cable. It should be remarked in this case that the channel is usually serpentine in form, the current is, as a rule, stronger on the concave than on the convex side, and consequently there is a tendency for the concave bank to become more concave, and for matter to be deposited on the convex side. The subject of the stability of river channels has great interest for the telegraph engineer, particularly in countries where the rivers, from their width or other cause, must be crossed by cable.

Section VI.—*Theory of Submersion, Recovery, &c., of Cables.*

184. A cable suspended in water, between two fixed points, hangs in a catenary curve; but when the cable is being raised from or submersed below the water, the conditions are altered, the catenary is more or less departed from, and its formulæ are

no longer applicable. Air offers no appreciable resistance to the motions of a wire or cable; but water offers a resistance to displacement, and there is sensible friction between water and a body moving in it, depending on the nature and area of the surface and the velocity of the moving body. Thus, a cable hanging perfectly still in water hangs in the same curve as the same cable would assume if suspended in air, and, the superior density of the water being considered, the same formulæ are applicable to the two cases; but immediately any motion is impressed on the cable the conditions are altered in the one case by the sensible resistance of the medium, and the conditions of the two cases are no longer similar. The ultimate elements to be considered are —the strength of the cable, its weight in water, the resistance the water offers to displacement by the cable, the velocity of the ship, the rate at which the cable is payed out, the depth of water, and the extent and nature of the surface of the cable as affecting friction. The proximate elements are—the rate of sinking, the angle of immersion, the length of cable actually sinking at each moment, and the velocity and direction of its motion. The weight of a cable in air and in water, and its tensile strength measured in its own length in air and in water, are ascertained by calculation, and checked by experiment, for each pattern cable.

185. The modulus of tenacity in the case of a cable is its ultimate load *in water*, measured in length of the cable itself; the working modulus is generally one-fourth of the ultimate modulus in water. Of a cable having the same or inferior specific gravity to water, the modulus would be infinite, and such cable would not run out from the ship by its own weight alone; cables having a specific gravity superior to that of the water they are to be laid in, have a finite modulus greater the less their specific gravity— they sink with greater or less velocity when cast into water. In this case, when the difference between the specific gravity of the cable and that of water exceeds a certain amount, the weight of the cable hanging in the water is sufficient to drag fresh portions of cable from the ship, and brake power becomes necessary to prevent the cable running out too fast. The latter is the case which occurs in practice, all cables hitherto laid being considerably superior in specific gravity to sea water.

186. If a detached piece of cable were dropped into water, it would sink in a vertical direction by reason of its weight in water; it would tend to fall with an accelerated motion, increasing with the time of falling in an arithmetical progression; but as the resistance of the medium would increase as the square of the velocity, a velocity would ultimately be attained at which

the force of gravity would be counterbalanced by the resistance of the medium, and the body would move with the velocity it had already acquired without further acceleration. As the force of gravity is balanced by the resistance of the medium, these opposed forces must be equal and opposite; hence the velocity of falling would be uniform when the upward pressure of the medium, by reason of the velocity, equals the weight of the body in water. The velocity acquired will depend on the extent and mode of application of the surface of the falling body; other conditions remaining constant, it will be less the greater the surface the more nearly perpendicularly the surface is presented to the pressure of the medium, and as affecting friction, the rougher the side surface. Thus, a long piece of cable dropped freely into water would sink quicker if immersed endwise than laterally; and it is evident, when immersed endwise, from the small extent of surface perpendicular to the upward pressure of the water, the retarding action of the medium must be sensibly due to friction only between the vertical surfaces of the cable and the water. Thus, the resistance of water—

$$R = Cv^2 ; \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1.)$$

C being a number dependent on the form, surface, &c., of the body, and found by experiment, and v being the velocity. When the velocity has attained its maximum and become constant $R = w$, the weight of the body in water; hence—

$$w = Cv^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.)$$

For an Atlantic cable weighing ·2575 lb. per foot in water, when sinking v feet per second perpendicularly to the direction of its length, C was found to equal about ·154 (F. Jenkin); hence, for this cable, the maximum velocity of sinking in this manner is (2)—

$$\text{foot } 1{\cdot}294 = \sqrt{\frac{0{\cdot}2575}{0{\cdot}154}}.$$

187. It has been assumed that the cable is entirely free to move, but this is not the case in practice. The object to be attained in laying a cable is to place it on the bottom without tension, but without unnecessary slack; hence, instead of allowing the cable to run out freely, it is restrained by tension at the ship; this tension modifies the line in which the cable sinks, causing each element to sink in an inclined direction instead of vertically, the

direction in which it would sink if acted on by gravity alone. To examine the conditions of submersion, let it be assumed—*Firstly*, that the bottom is horizontal, and that the cable is laid in a straight line on the bottom without any tension. As each portion of the cable passes into the water, it tends to sink vertically by reason of its weight; let this vertical force be resolved into two rectangular components, one at right angles to the cable, and the other in the direction of its length. The former component does not affect the tension on the cable—it is opposed by the resistance the water offers to displacement by the cable moving in its direction, and it affects the inclination of the cable to the horizon, termed the angle of immersion; the other component affects the tension on the cable, and is opposed to the friction between the cable and the water, and the tension at the ship due to the action of the brake. The resistance of the water to the motion of the cable, either in the direction of its length or at right angle to that direction, is dependent on the velocity of motion in the given direction, being directly as the square of that velocity.

188. Considering only the component at right angles to the cable's length, the resistance of the water perpendicular to the direction of the cable supports the latter as an inclined plane, and causes it to lie in a straight line. The angle of immersion depends on the relation between the velocities of the ship and of the cable in a direction perpendicular to its length. If AB, fig. 37, be the surface of the sea, CD the cable, and if the ship move from C to B while the element of the cable C moves to E, the relation between the lines CE and CB, representing the velocities of ship and cable respectively, are $\frac{CE}{CB}$, or the sine of the angle of immersion ACD, or CBE; hence the sine of the angle of immersion expresses the relation between the velocities of the cable at right angles to its length, and of the ship. If of the three quantities—the angle of immersion, the velocity of the cable, and the velocity of the ship—two be known, the third may be readily found from the formula: $\frac{v}{v_1} = \sin$ (3), in which v_1 = velocity of ship, v that of cable perpendicular to its length, and ϕ = angle of immersion. The resistance of the water to the motion of the cable perpendicular to its length is given in formula (2). The velocity v is

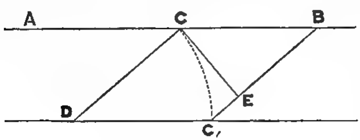


Fig. 37.

less than $\sqrt{\frac{w}{c}}$, because the cable is not suspended horizontally; for as only one component of the weight is considered, and the components are taken at right angles to each other, the rate of motion cannot exceed $\sqrt{\frac{\cos\phi\ w}{c}}=v$; $\cos\phi\ w$ being the value of the component of the weight of the cable in the direction perpendicular to its length. Thus the Atlantic cable, weighing ·2575 lb. per foot in water, could not sink faster than—

$$\sqrt{\frac{\cos\phi\ \cdot 2575}{\cdot 154}}=v,$$

when oblique to the horizon. The weight of the cable overcomes the resistance of the water with a velocity which increases with this weight in water, directly as the cosine of the angle of immersion, and inversely as the co-efficient of the resistance the water offers to the motion of the cable. The introduction of the cosine is in accordance with the parallelogram of forces; it is evident, in considering the component of the weight perpendicular to the cable, that this has a less value the greater the angle of immersion, and when the cable is immersed at right angles to the surface of the sea, or vertically, this component vanishes. The velocity of sinking at right angles to its length, and the angle of immersion, are not affected by the length of cable in motion, as the resistance of the water acts equally on each portion of that length.

189. Considering now the component of the weight taken in the direction of the cable's length, this component is equal in magnitude to the weight of the cable in water, multiplied by the sine of the angle of immersion—it is opposed to the friction of the water and the tension at the ship. As the cable lies in the water as if it were on an inclined plane moving in the direction of the vessel, the tension at the ship is less than if the length of cable hanging in the water were suspended vertically, and is equal to the weight of a piece of cable as long as the depth of the sea. Therefore the tension on the cable is not increased by diminishing the angle of immersion; so long as the depth remains constant, it is independent of the length of cable actually suspended in the water at any moment, the friction between the cable and water being neglected. Thus, if the vessel be urged at an increased speed, the angle of immersion will be reduced, a greater length of cable will be on its way to the bottom at each moment, but (friction being neglected) the tension on the cable at the ship

will remain the same. If, in fig. 38, AC be the cable from the ship at A to the bottom at C, if a pulley be conceived at A, and a length of cable AB continuous with CA, and equal to the depth of the sea, be suspended over the pulley A; then the weight of AB will balance that of AC lying on the inclined plane of water, friction being neglected. For by the parallelogram of forces the weight 2 3 of CA, being resolved into two components—viz., 1 2 and 2 4, 2 4 = 2 3 × cos ACB, and 1 2 = 2 3 × sin ACB, the triangles are similar, and AB = AC × sin ACB, ∴ the weight of AB will balance the component of the weight of AC in the direction AC whatever the angle ACB, or the length AC, the cable being assumed free to move on the inclined plane AC without friction. Hence the tension at the ship, when the cable is laid in a straight line on a horizontal bottom, without slack, is— $T = wh - f$...(4); in which w is the weight in water of a unit of length of the cable, h is the depth, and f is the resistance offered by the water to the cable's motion longitudinally.

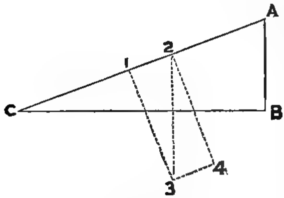


Fig. 38.

190. The quantity f sensibly affects the result, and its value remains to be examined. The value of this quantity is assumed to vary directly as the square of the velocity with which the cable moves longitudinally; it varies directly as the amount of friction on each unit of the cable's length, and directly as the number of units of length in motion. In fig. 37, if DC represent the cable, and DC_1 the level bottom of the sea; in moving from the position DC to C_1EB the element C will not move in the line CE at right angles to the cable; instead of arriving at E the element C will arrive at C_1, for $DC_1 = DC$. The cable being laid without slack, in moving from the first to the second position it will have slipped through the distance EC_1, equal to the versed sine of CDC_1, the longitudinal velocity of the cable therefore is—

$$v_{11} = v \times \text{ver sin } \varphi. \quad \ldots\ldots\ldots\ldots\ldots\ldots(5.)$$

If the cable leave the ship at a velocity v_{111} superior to that of the ship, then the longitudinal velocity is—

$$v_{11} = v \times \text{ver sin } \varphi + (v_{111} - v). \quad \ldots\ldots\ldots\ldots\ldots(6.)$$

The resistance offered by the water per unit length of cable moving *longitudinally* with the unit velocity, is termed commonly the co-efficient of friction; it depends on the extent and nature of

the surface of the cable, being greater with rough than smooth surfaces, and with cables of large than small diameter. The law in which the resistance varies with these conditions is not known, it is sometimes assumed equal to the product of the diameter of the cable by a co-efficient obtained by experiment; for the Atlantic cable of 1866 it was found the resistance per foot of cable to the motion of the cable longitudinally was ·0085 lb. (Longridge); ·007 d for hemp-covered, and ·001 d for iron-covered cables (Clark and Sabine), are approximations considered sufficiently near for practical purposes, d being the diameter in inches. The value of the co-efficient is difficult to determine; there is a general agreement concerning the formulæ, but different values are given by several authors to the co-efficient; as, however, there is always a percentage of slack allowed more than sufficient to cover inaccuracy in this particular, and cables are not purposely loaded to so near their breaking points as to render the inaccuracy of consequence, no practical difficulty arises from the use of an approximate value. The frictional resistance is directly as the length of cable in motion; this length l is directly as the depth of the sea, and inversely as the sine of the angle φ, *i. e.*—

$$l = \frac{h}{\sin \varphi}; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7.)$$

thus, f (4) is given by the formula—

$$f = v_{11}^2 \times c_1 \times l; \quad \ldots\ldots\ldots\ldots\ldots\ldots(8.)$$

c_1 being the so called co-efficient of friction. Substituting the values, the cable passing out at a greater velocity than that of the ship, the case in practice—

$$f = (v \times \text{ver} \sin \varphi + v_{111} - v_1)^2 \times c_1 \times \frac{h}{\sin \varphi} \quad \ldots\ldots\ldots(9.)$$

191. Dividing the quantity in brackets by v_1, placing v_1^2 outside the brackets, and substituting for the versed sine 1 – cos:—

$$f = \frac{c_1 h v_1^2 \left(\frac{v_{111}}{v_1} - \cos \varphi\right)^2}{\sin \varphi};$$

and (4) becomes

$$\mathrm{T} = h\left\{w - \frac{c_1 v_1^2 \left(\frac{v_{111}}{v_1} - \cos \varphi\right)^2}{\sin \varphi}\right\}; \quad \ldots\ldots\ldots(10.)$$

a formula agreeing exactly with that given by Messrs. Clark and Sabine (*Tables and Formulæ*) on the authority of Mr Long-

ridge. If the second member of the equation be multiplied by ·0536, and h be fathoms, the quantity T will be in hundredweights; pounds and feet being used within the brackets. From the above it is evident that the strain on the cable is reduced when $\frac{v_{111}}{v_1}$ is increased in value by increasing the percentage of slack, and the same effect is produced by increasing the speed of the ship v_1, maintaining the relation $\frac{v_{111}}{v_1}$ constant.

192. If the ship be stopped, the tension is no longer reduced by the friction and the resistance of the water perpendicular to the cable's length; the cable forms a catenary; and hence, if it become necessary to stop the ship, the cable should be allowed to run out to reduce the angle ϕ nearly to 90°, and the tension as nearly as possible to hw, the least value it can have when the paying out has stopped; for in this case there is no tension at the bottom of the sea. If the cable hang obliquely, there is tension at the bottom, and the cable is under the action of three forces in equilibrio—viz., the tension at the bottom, the weight of the cable, and the tension at the ship; as it hangs in a catenary curve, the tension at the ship exceeds that at the bottom by an amount equal to the weight of a length of cable equal to the difference in level —*i.e.*, the dip of the curve, or the depth of the sea. Thus, if T be the tension at the ship, $T - hw$ will represent the tension at the bottom. T is the resultant of the weight and the tension at the bottom; by the parallelogram of forces each component is equal to the product of the resultant and the cosine of the angle between its direction and that of the resultant; hence $T - hw = T \cos \phi$; transposing and expressing the division—

$$T = \frac{hw}{1 - \cos \phi}; \quad \text{.....................(11.)}$$

This tension may be expressed in terms of hw; let $T = xhw$, then

$$x = \frac{1}{1 - \cos \phi}; \quad \text{..................(11 A.)}$$

x represents the tension when the cable hangs at the angle ϕ, in terms of the minimum tension hw. From this formula it follows: when $\phi = 90°$ the tension $x = 1$, or $hw \times 1$; when the angle $\phi = 0°$, then $x =$ infinity; for $\phi = 5°$, $x = 262·8$, or T equals $262·8 \times hw$, &c.; and generally, x represents the tension measured by the weight of a length of cable equal to the depth of the sea. A table calculated from this formula is given by Messrs. Clark and Sabine, on the authority of "Airy," as a "Table of the tension of cable when

payed out at different angles;" but this is incorrect, the formula does not apply to a cable during paying out, it is true only when the cable is hanging stationary. Observation of tensions and angles in practice proves that a cable does *not* hang in a catenary during paying out, and confirms the theory stated above.

193. This formula is useful to calculate the strain on a land line at the supports, when the difference of level between either of the points of support and the lowest point of the curve, and the angle made by the wire with the horizon at the insulator, are known. The angle at one of the insulators being measured with a clinometer, and the dip being known, the tension at the insulator may be calculated; and when the supports differ in height this may be calculated for each support. If the tension on the wire be known, the dip may be readily calculated from this and the inclination at the insulator. Some values of x are given in the following table :—

Angle with Horizontal line.	Tension measured by weight of a piece of wire or cable equal in length to the dip.
5°	262·8
10°	65·8
15°	29·4
20°	16·6
25°	10·7
30°	7·47
35°	5·53
40°	4·27
45°	3·47
50°	2·80
55°	2·35
60°	2·00
90°	1·00

194. The formula (11 A) evidently represents the tension on each side of a bight of cable hanging stationary in the water, suspended from a grapnel; as the cable is free to slip longitudinally on the grapnel, the tension on each side of the bight is balanced by that on the other side, and hence these tensions are equal. The tension on the grapnel rope T_1 being the resultant of these equal forces, is equal to one of them multiplied by the cosine of half the angle formed by the bight, or—

$$T_1 = \frac{hw}{\sin \phi \, (1 - \cos \phi)} \text{ ;} \ldots\ldots\ldots\ldots\ldots\ldots (12.)$$

195. When a cable is lifted, the friction and the resistance to

displacement offered by the water do not act, as in the case of submersion, to diminish the tension on the cable; they act in opposition to the lifting force, and hence increase this tension, and consequently the load on the grapnel rope also. As the friction and resistance to displacement increase with the square of the longitudinal and transverse velocities of the cable respectively, it is of great importance in lifting a cable to do so slowly. If the cable be raised on the bight the conditions are the most severe, for the angle of the bight cannot be reduced; if the end is on board, the load on the cable admits of reduction by, as far as practicable, causing the vessel to move over the track of the cable with such velocity, relative to that of the taking in of the cable, as to keep the angle ϕ as large as possible. To obtain the load on a cable while being lifted, it is necessary to add to the tension due to the cable hanging in a catenary the additional resistance due to friction and resistance to displacement. The value of the resistance due to friction is obtained as explained in Paragraph 190. The value of the resistance to displacement may be obtained by means of (2); for C having been ascertained by experiment, the resistance to a cable moving in a direction perpendicular to its length with velocity v is Cv^2; but as the caole is raised at an angle, this resistance is reduced as the cosine of the angle it makes with the horizon ϕ, hence this resistance per foot $R = Cv^2 \cos \phi$. As cables are raised at considerable angles with the horizon, $\cos \phi$ is usually small, and v is also kept small.

PART II.

PROPERTIES AND APPLICATIONS OF MATERIALS—OPERATIONS AND MANIPULATION.

CHAPTER I.

NON-METALLIC MATERIALS NOT INSULATORS PROPER.

SECTION I.—*Wood and its Application.*

DIVISION I.—PROPERTIES, PRESERVATION, AND CARPENTRY.

196. WOOD has the organised structure and complex composition common to organised bodies; it is composed of spindle-shaped cells, or of tubes primarily of cellulose, more or less thickened by the deposition in their interior of lignine, which renders their walls impermeable to fluids and gives the wood its stiffness. Cellulose forms the basis of vegetable tissues, and is allied to starch. Lignine is not coloured by iodine, and has a slight trace of nitrogen in its composition. *Woody fibre, ligneous tissue*, or *pluerenchyma*, in its early state contains and conveys fluids, but a deposit of lignine ultimately obliterates the vessels. Woody tissue contains naturally more or less of the organic substances albumen, caseine, starch, sugar, &c.

197. As obtained from the plant, wood is liable to alteration chemically by the fermentation of its contained fluids, and mechanically by exudation of these fluids. The form and volume is altered by drying (shrinking, warping). Unless dried either with the bark on, or slowly and with certain other precautions, the wood in the process of drying cracks in the direction of the fibres. Alteration in form, and the existence in the wood of organic products favourable to decay, attractive to insects, and conducive to the destruction of the wood by fungi, render wood in its natural state inapplicable to most purposes to which prepared, dried, or seasoned wood is applied. Not only is dried or seasoned wood more permanent in volume and shape, and more durable, but it is stronger than wood as obtained from the plant, and of course lighter; but unseasoned wood is easier to work.

The resistance offered to crushing is sometimes doubled by drying, and by the ordinary process the heaviness is reduced by one-third; when quite dry, some kinds are reduced to half their original heaviness. From the above it is apparent that water and unstable organic compounds should be, so far as practicable, extracted from wood to give it its maximum durability, permanence of form, &c.; and for many purposes to which wood is applied, the shrinking and splitting of the wood would either cause the work to fall to pieces, or so loosen the joints as to render the work unserviceable. It is also evident, in the event of wood being necessarily used in its unprepared state, no impediment should be placed in the way of the exudation of its moisture, by tarring, painting, &c.

198. Injury to the organised structure of wood is prejudicial to its strength, and should therefore, so far as possible, be avoided. For this reason the abstraction of its products cannot be indefinitely hastened without impairing the strength of the product. Split wood is stronger than sawn; wood round from the tree is stronger than squared timber; and in pile-driving a pile cut with the pith of the tree in its centre, is found less liable to split than one cut from superior timber in which this condition is not fulfilled, as when four piles are cut from one tree. In consequence of the organised structure of wood, its tenacity is greater with than across the grain; and a square prism of wood bends easier across two of its opposite sides than across the other two sides, provided the pith of the tree be not in the centre of the prism.

199. Useful wood is produced by both endogenous and exogenous plants, the bamboo and palms are instances of the former. Wood from endogenous plants is however, of very limited application, being too slender and flexible for the majority of purposes to which wood of exogenous plants is applied; but, being light and tough, it is very useful for many purposes. It frequently happens that little or no care is taken in selecting endogenous wood, and in removing from it fermentable matter, and hence its durability is underrated.

200. The stem of an exogenous tree supplying wood encloses in its centre the pith; during the first year this is cellular, full of fluid, and occupies a large portion of the stem. The pith is enclosed in its sheath (the medullary sheath); around this is formed, in the first year, a layer of fibres or fusiform cells, a similar layer is formed in each succeeding year; the pith becomes indurated, it does not increase in size, but is never obliterated. The layers of fibres thus deposited are at first permeable by fluids, but beginning nearer the pith, ligneous matter is deposited in their interior until they are rendered impermeable and their cavities almost filled. The layers nearer the pith in which this

thickening has taken place, is termed the *duramen* or *heart-wood*, and this is the wood preferably employed in the arts; the outer layers, in which the fibres are still permeable by fluids, is termed the *alburnum* or *sap-wood*. The division between these is generally distinctly marked. The fibres or tubes are connected together by their membranous coats. Dr. Boucherie found a coloured fluid injected at one end of a log to form the name "Faraday," appeared at the other end of the log forming the letters distinctly, proving there was little or no lateral diffusion of the fluid. The pith and the bark are connected by the medullary rays or silver grain of the carpenter, these appear as narrow lines running from the centre to the circumference; they are usually continuous from the pith to the bark, but occasionally secondary rays arise from the bark not reaching so far inward as the pith; they are not continuous from the base to the summit of the tree. The principal shrinkage in drying is perpendicular to the medullary rays. The bark grows by addition to its inside surface, while the wood grows by addition to its outside, hence the bark is continually distended. The sap ascends annually from the roots to the leaves, probably principally through the outer layers of wood, hence called sap-wood; it descends chiefly by the bark, and detaches the bark from the wood immediately beneath it; the space thus formed is filled with sap, which forms a new concentric layer of wood. The successive layers are separated by lines more or less distinct, in which the wood is more porous and darker than between these lines; hence the number of rings between the centre and the bark exhibited by a cross section of the trunk of a tree generally indicates the age of the tree. Cedars, planes, oaks, and limes have been found by the rings at least 1000 years old; and as many as 6000 years have been assigned to some trees. Interruption to growth, however, may cause several rings to be developed in one year; and sometimes in hot climates there is so little difference of activity at different seasons, that the zones cannot be accurately defined. The width of the zones varies in different trees, and at different periods of the life of the tree; they are usually broad in soft-wooded trees and narrower in old than in young trees. If a tree be unequally exposed to light and air, the zones will be wider on the side more exposed, and the pith will be eccentric. Wide zones are generally an evidence of rapid growth; they appear to be wider at a certain period of the plant's life, differing with the nature of the plant—*e.g.*, the most rapid upward growth of oak is in the first ten years, the rate gradually diminishes till the thirtieth year, and then more rapidly; this slow increase, after a certain period, is a reason why trees are often felled by the grower before they are

mature. Branches are similar in structure to the trunks they spring from—they have of course fewer annual rings. A branch causes a distortion and perforation of the fibres of those layers of the trunk formed after the branch had commenced to sprout; this perforation and distortion constitute what is commonly known as a knot.

201. The proportion between the heart-wood and sap-wood varies with the kind of tree, its age, and the soil on which it is grown:—in three specimens of medium quality, diameter = 1, it was—oak ·294, chestnut ·1, Scotch fir ·416; probably there is an average number of layers of sap-wood, or an average thickness for each kind of tree. When a tree has passed maturity decay commences with the pith; the centre of the tree becomes spongy or hollow, and the heart-wood proceeding from the pith becomes brittle and weaker than the wood more removed from the centre, and than the wood equally distant in the younger tree. The growth of trees is at first principally upwards, and after the full height has been gained the branches increase and spread. The mean heights in feet of the trunks of some trees are, ash 38, beech 44, birch 47, box 15, chestnut 44, elm 44, fir 57, oak 44, northern pine 47, plane 44, sycamore 31, walnut 47. Heart-wood differs from sap-wood in its cells being filled with lignine, while in sap-wood the cells still remain hollow, and have their walls more or less permeable to fluids. Heart-wood is in many trees darker, it is much closer in texture, harder, specifically heavier, stronger, and more permanent in form and volume than sap-wood; it increases in hardness, and becomes more homogeneous as the tree approaches maturity; after which it deteriorates from the centre. As all sap-wood decays rapidly, is inferior to heart-wood in strength, stiffness, and hardness, and is very liable to be attacked by insects, even in those trees whose heart-wood is never attacked, its employment is avoided as much as possible.

202. In temperate climates the sap rises during the spring and leaves are developed; in summer the sap almost ceases to flow, and vegetation remains stationary; in autumn the sap descends and the leaves fall off; in winter the tree becomes again inactive. In tropical climates the dry season is the period of inactivity. While the sap is flowing the bark becomes loose, the condition of the tree can be thereby ascertained. The best seasons for felling trees are when the circulation is least active—viz., the middle of the summer or winter periods of quiescence, and during the dry season in tropical climates. Trees containing much sap-wood should be barked in the spring and felled in the succeeding winter; by this treatment the strength and the

durability of the sap-wood are increased. In the Himalayas coniferous trees are barked in the spring, when the sap is rising, and felled at the end of October; the sap-wood is said to be rendered by this treatment almost as strong and durable as the heart-wood. In Norway, to obtain a greater quantity of turpentine in the wood, and render it more solid and durable, they ring the bark of the branches just before return of the sap, the next year they ring the upper part of the stem, the third year the centre, and the fourth year the lower part. Some trees are better felled at midsummer, but the greater number are better felled in winter. Trees felled at an improper season are less durable, being more liable to attacks of certain insects, and to decay from fermentation of their contained juices; but this is of most importance when the tree contains much sap-wood.

203. Strong and durable wood of any particular kind is distinguished by its close texture, its greater specific weight, freedom from knots and faults, if coloured by its darker colour, by its absorbing little water when immersed, and by straightness of grain. The centre should be sound, and neither spongy nor hollow, nor should soft or hollow places, indicating decay, appear elsewhere. The fibres should be strongly adherent, should cut off short and not be torn by the saw. Of wood of the same kind containing resin, gum, or sap, that containing least is generally considered strongest; and the presence of resin does not necessarily increase durability. Wood in which the annual rings and medullary rays are most marked is generally least homogeneous, and most liable to warp. Twining plants, by interfering with the circulation of trees, injure the quality of timber; but these do less damage to endogenous trees, the latter being protected by the hardness of their bark. A knot or other hidden fault in a long piece of wood may often be discovered by supporting the wood at both ends and loading it in the centre, if a fault exist the curve of the beam will be affected by its presence. Hollowness is detected by boring with an auger, the tool should be frequently withdrawn and the cuttings examined. Quickness of growth, as evidenced by wideness of the annual rings, is stated to be prejudicial to strength. But Mr. Barlow found by experiment quickly grown oak was stronger than that grown slower; and quick growth is stated by him to be a sign of vigour, and a proof of good quality in the wood. There is, however, much difference of opinion on this point; the strength must depend on the circumstances under which the rapid growth occurs; thus, excessive heat and moisture, with poor soil, may induce a rapid growth of bad wood. During the most vigorous period of a tree's life the rings are wider than earlier or later.

To obtain the most wood of the best quality, and to avoid sap-wood, the tree should be felled at maturity; the time required to reach maturity for a few of the most useful trees is given below:—

	Age at Maturity. Years.
Oak,	60 to 200 average 100
Ash, Elm, Larch,	50 to 100
Fir,	70 to 100
Poplar,	30 to 50
Norway Spruce and Scotch Pine,	70 to 100

Trees grown too closely together are imperfectly nourished, the functions of the leaves being interfered with, and the roots not being thrown out vigorously. Firs should be grown at least 6 to 8 feet, and hardwood trees 28 feet apart. Trees grown in sunny and exposed localities furnish stronger and more durable wood than trees grown in shady moist places; stagnant water is very prejudicial to strength and durability. Alder, ash, beech, poplar, walnut, and willow, are the principal trees growing in moist places; pine and cedar grow best in sandy elevated places. Trees supplying the strongest timber are indigenous to warm climates; but of trees of the same kind, those grown in the colder climate supply the strongest and most durable wood. This is attributed by some authorities to slower growth in the cold climate; but difference of opinion exists on this point. Trees should be selected with well-developed roots, and should not have dead branches, particularly at the top; the bark should be uniform, and the trunk regular in shape. Frost causes trees to crack, and high winds cause separation of the annual layers; with the latter fault wood is said to be rolled. Clean stuff is wood without knots or sap-wood; free stuff is clean and planes without tearing; frowy stuff is soft in texture, and its fibres are brittle; in cross-grained wood the fibres have twisted in growth.

204. The term *timber* is applied to trees measuring 2 feet and more in girth; all timber trees properly so called are exogenous. While the tree is living the wood is called *standing timber;* when felled, *rough timber;* with the outside pieces sawn off, *squared* or *sided* timber; the largest square log which can be cut from a tree is termed a *baulk;* the outside pieces sawn off are termed *slabs.* When sawn up, timber is said to be *converted;* it is called *scantling* when in large pieces, *planks* and *boards* when in thin pieces. A board 11 inches wide is termed a *plank,* and less than 7 inches a *batten.* A piece of wood 70 to 80 feet long,

and 18 inches to 25 inches diameter, is termed a *mast;* smaller than this, a *spar*. A baulk cut longitudinally through the diagonal of its section is said to be cut *arris-wise*.

205. Timber for purposes of carpentry is classified as *coniferous* or *fir wood*, and *non-coniferous, hard*, or *leaf wood*. Fir wood is generally straight in fibre, regular in figure, and, from the lateral adhesion of its fibres being small, is easily divided along the grain; pine, fir, larch, cowrie, yew, cedar, juniper, and cypress, are examples of this class. Non-coniferous woods do not contain turpentine; they are, generally speaking, less regular in texture than fir wood, and better adapted to bear shocks and resist stress across the fibres.

206. Timber may be felled at the proper season either by the tree being cut down at once, or by a ring being cut round it through the bark and into the sap-wood, so as to cut off the supply of sap to the upper part of the tree, after which the tree is left standing a year to die and dry, when it is cut through. The latter mode is used when the object is to improve the quality of the sap-wood. A saw is the more economical instrument for felling; but if the axe be used, the patterns in general use in the country will, as a rule, be found preferable in the hands of the native to foreign patterns; this applies also to other wood-cutting tools, as dhaws, kookeries, &c., used for clearing. To fell a tree with the axe, commence on the side the tree will fall, and cut a deep wedge-shaped opening half through, then cut on the other side until the tree falls. Having felled the tree, it has to be prepared for use by removing as far as possible its fluids, and by shrinking it slowly that it may not split in the drying or after having been made up; by shrinking it thoroughly, its future shrinking or warping is reduced to a minimum, the process is termed drying or seasoning. Some woods warp more than others in drying, and hence it is more necessary to be assured such woods are dried before they are made up. For some purposes, as for joinery, it is essential the wood be thoroughly seasoned; but for other purposes, as telegraph posts, although seasoned timber is much to be preferred, wood has frequently to be used before it has been seasoned; in this case the conditions favourable to seasoning should be as far as possible presented (Paragraph 197.) After felling, the log should be roughly squared by sawing off four slabs; large logs for masts are cut into octagonal prisms, a shape also commonly given to hardwood timber for posts. Firs for telegraph posts are only barked and planed. If the logs are to be cut up they may be halved or quartered at once. Sometimes timber is allowed to lie six months before squaring; but the object in squaring is to prevent the timber cracking by unequal

contraction, and to hasten the drying. When the difference in structure between sap-wood and heart-wood is considered, it will be evident the former may be expected to shrink more in drying; while being placed outside the latter, the tendency of drying must be to split the wood. Timber should remain one year in scantling before being cut thin, or it may warp and split. Wood split in seasoning is said to be *shaken;* a quadrilateral piece of timber, concave between two opposite corners and convex between the other two, is said to *wind*, be *winding*, or to warp. Timber to be used full size for beams or masts may be bored from end to end with advantage, as the liability to split in drying is thereby reduced. The logs should be removed from the forest as soon as possible, and placed perpendicularly or nearly so, the lower end being raised from the ground, in a well-drained place, exposed freely to the air, but sheltered from wind and sudden changes of temperature, the object being to dry the wood gradually. If the wood cannot be sheltered, it may be plastered with cow-dung and mud as a substitute; if it cannot be raised in the manner directed above, it may be placed horizontally, supported on iron or stone, allowing a free circulation of air round each piece. Waste wood should be excluded from the timber-yard as favourable to insects and fungi, which might attack unseasoned wood. This method of seasoning is termed the natural method; for carpenter's work two years, and for joinery four years are the usual periods allowed before the wood is made up. When fit for carpenter's work it is said to be seasoned, when fit for joinery it is said to be dried, but it is not then perfectly dry; English oak, for example, cannot be thoroughly dried in much less than twenty years. The periods necessary to season or dry wood depend on the size of the pieces; in the open air, logs $10' \times 6'' \times 6''$ are seasoned in eleven months, and dried in twenty-nine; logs $20' \times 20'' \times 20''$ are seasoned in thirty-six months, and dried in ninety-six (Tredgold). The loss of weight and shrinkage per cent. in a few cases (collected by Rankine) is as follows:—

	Loss of Weight per Cent.	Shrinkage per Cent.
Pine, ...	12 to 25	2 to 3
Larch, ...	6 to 25	2 to 3
Oak, British, . . .	16 to 30	about 8
Elm, ...	about 40	

The loss of weight is used as a test of seasoning, it varies with the age and quality of timber, soil, &c. Timber is fit for carpenter's work, according to Rondelet, when it has lost one-sixth;

according to Tredgold, when it has lost one-fifth of its weight; dry timber for joinery should have lost one-third; these proportions must vary considerably in practice.

207. The natural method of seasoning is the best, the product having its maximum strength and durability, but the time it takes is a serious disadvantage; hence quicker modes of seasoning have been devised. The principal of these are—water-seasoning, steaming, boiling, immersion in a dunghill, and desiccation by a current of hot air. Water-seasoning: the timber is completely immersed in water (running if possible) as soon as cut, care being taken that it is sunk below the surface; after soaking a fortnight, it is gradually dried as in natural seasoning; it is fit for carpenter's work in six months. This process removes more matter than natural seasoning, it is very suitable to timber cut with the sap; the product is weaker than that obtained by natural seasoning, but the sap-wood is probably more durable. Immersion for a fortnight would no doubt increase the durability of unseasoned telegraph poles, by rendering them better able to resist the effects of exposure, than they would be if squared and erected at once; and by hastening the seasoning, render it practicable to apply a surface protector at an earlier date after erection. Water-seasoning is very generally applied to endogenous wood, particularly bamboos; these in Bengal are immersed for a fortnight or three weeks after felling. They are usually felled in October or November. Boiling and steaming for a few hours reduces the liability to shrink, but impairs the elasticity and strength; boiled or steamed wood shrinks less than timber naturally dried. The boiling is continued one hour for each inch of thickness, but not exceeding four hours. This mode of seasoning is useful for wood required to be prepared quickly for joiner's work, for which purpose wood so prepared stands better than when naturally seasoned. Boiling and steaming are also used in bending timber. Immersion in a dunghill is a slow steaming; it is said to give good results, but is of very limited application, as the quantity of timber which can be seasoned at one time is necessarily small. The strength of Babul is said to be increased by boiling, this is explained by Dr. Paton by the wood being saturated with tannin. The wood is boiled with the bark on as soon as possible after felling, after boiling it should be carefully dried. Desiccation by a current of hot air has been applied to the seasoning of timber, it is the most successful method of artificial seasoning. Shrinking and warping are lessened by painting and varnishing, but wood is always liable to swell and shrink under extremes of moisture and dryness respectively; thus, in India woodwork swells in the wet season and

shrinks in the hot weather; this occurs more or less however old and dry the wood may be. A board cut radially from the tree warps less than one cut in any other direction; other boards become convex towards the centre of the tree, hence in joining planks, &c., sideways, they should be so arranged that the tendency of each to become convex on one side of the work may be neutralised by the tendency of others to become concave on the same side, and *vice versâ*, the work will then remain flat.

208. Timber, under favourable circumstances, has very great durability. There are specimens of carpentry in roofs, still in good preservation, one thousand years old, and there are numerous examples five hundred years old. Exposure to the sun, wind, and alternations of moisture and dryness, causes timber to assume a bluish-gray colour, to lose elasticity, and to crack and open into numerous fissures longitudinally, exposing successively greater surface to the atmosphere and more openings for the lodgment of moisture. In the case of telegraph poles in a tropical climate the atmospheric conditions are very trying to the timber. That this deterioration is due to exposure is proved by the fact that it does not go on under ground. Posts badly decayed above ground, and considerably reduced in girth thereby, are frequently found perfectly preserved under ground. To preserve timber against this influence of exposure is the object of surface protection, as tarring, painting, &c. The timber having been well dried, the surface may be protected by one of the following preparations:—1. Oil paint; 2. hot oil (linseed, gurjon, &c.); 3. a mixture of equal parts of oil (mustard or linseed) and coal tar, used hot; 4. the wood may be charred on the surface, and then hot oil or a mixture of oil and tar applied. This is very efficient, and is used for timber to be inserted in the earth. The wood should be charred to rather less than an inch deep, being protected from the outer air during the process; the oil or tar should be applied immediately; the protection should be extended to 6 inches or 1 foot above the earth line, as at this part and just above it posts often decay more rapidly than elsewhere. 5. Dipping entirely in boiling creosote, or only to 6 inches above the ground; this is successfully applied to hop poles in Kent. 6. Earth oil, this is used where cheap—viz., in Burmah and some parts of Lower Bengal. In painting wood to be exposed to the weather, several coats of linseed oil should be put on first and allowed to soak in; the durability of tarring and painting may also be greatly increased by sanding the surface while wet. As resins are not more durable than woody fibre, a surface protector requires periodical renewal on exposed surfaces. Wood alternately at short intervals wet and dry, is destroyed by wet rot; surface

protection protects timber against this source of decay. Wood placed in confined and unventilated situations, without excessive moisture being present, decays by dry rot; this is accompanied by the growth of a fungus, and timber so attacked is ultimately reduced to powder. Dry rot is not prevented by surface protection; in the case of imperfectly seasoned wood surface protection favours it. Wood is also liable to destruction by insects, the most destructive in India being the white ant and the goon; and there are several kinds of worm which destroy timber placed under water. Some kinds of timber are more liable to the attacks of insects than others; in some the sap-wood only is attacked. Teak, saul, and iron-wood are not attacked by white ants; these woods require no protection. According to Major Sankey's experiments, to these must be added arjoon and eyne; and bejar sar and seesum are only attacked in the sap-wood. The foot of a mast is best protected from the attacks of insects by a sheathing of sheet zinc, put on with zinc-coated nails, and continued to two feet above ground. If the mast be tarred, the zinc is soon corroded through by the acid of the tar; in this case Muntz metal or copper should be used. To protect wood from dry rot and the attacks of insects, it is injected—1. With poisonous metallic salts, forming insoluble compounds with the constituents of the timber; or, 2. Firstly with one salt, and secondly with another, that by chemical reaction an insoluble salt may be deposited in the timber; or, 3. With an antiseptic, which at once keeps away insects and preserves the timber. Of the metallic salts, the sulphates of iron and copper, bichloride of mercury, and chloride of zinc have been successfully applied; but these salts are gradually removed by the continued action of water. Injection with sulphate of copper is applied to telegraph poles in France by Dr. Boucherie, and it increases greatly their durability; small objects, as cords, &c., are prepared by mere soaking. Wood in large pieces, some time after felling, is placed in a closed vessel, subjected firstly to a current of steam; the vessel is then exhausted, and the solution allowed to enter and penetrate the wood. The method proposed by the inventor and most generally applied in France is, to inject the wood as soon as possible after felling. A cap is fitted to one end of the log, this end is placed 3 feet higher than the other end, the solution is admitted to the cap by a tube, and the pressure is obtained by raising the vessel containing the solution on a scaffold 23 to 26 feet high; the sap is driven out, and the solution takes its place. The best strength for the solution is 1 part by weight of the salt to 100 parts of water, and ·33 lb. of the solid salt is sufficient per cubic foot. The advantages of this process are its cheapness and simplicity;

the trees may be injected where felled; three days is the average time required to inject a 25 feet pole. The most successful process is Bethell's, in which the timber is saturated with creosote. The wood is enclosed in hermetically closed vessels, and the creosote is injected as described above in the case of sulphate of copper. The pressure used ranges from 5 to 10 atmospheres—the nearer the latter figure the better. The inventor considered 7 lbs. of creosote per cubic foot sufficient, but this depends on the kinds of wood to be injected; for marine work 10 lbs. is considered sufficient, and 12 lbs. has been required by some engineers; in hard woods it is sometimes difficult to inject more than 2 or 3 lbs. This process is esteemed most highly of all processes for preserving wood, which it protects against white ants, dry rot, and marine worms. Telegraph poles, properly injected, have been found well preserved after standing ten to fifteen years in temperate climates. The process has not been fairly tried in tropical climates on telegraph poles; it has been applied to railway sleepers and marine work, but the cases are not similar. It is not known how long the oil would be retained under tropical heat and rains. Injection is of little use unless thoroughly done, whatever liquid is employed; posts prepared with sulphate of copper sometimes decay almost as rapidly as unprepared wood, having been imperfectly prepared, and failure from the same cause is experienced in using Bethell's process. Injection with creosote is coming into more general use for telegraph poles; it has not the simplicity of the Boucherie process, and can only be employed where transport is cheap. A modification of the Boucherie process is employed in Norway; holes are bored in the sap-wood of standing poles and filled with solution or powdered sulphate, and stopped. Iron in contact with timber generally rusts rapidly and injures the wood; this is particularly the case with oak, and probably least so with teak. Iron fastenings should be protected by galvanising, by dipping the iron previously heated to the temperature of melting lead into boiling coal tar or cold linseed oil, or the iron may be painted with oil paint, renewed from time to time. Galvanised iron is sometimes attacked when used with oak. Galvanised fittings to telegraph posts, when loose, are occasionally tightened by the insertion of pieces of ungalvanised iron between the timber and fitting; this is objectionable, as the iron inserted rusts, injures the timber, and the fittings become looser than before; wedges of hard wood should be preferred. The conditions most favourable to the preservation of timber are good seasoning, free circulation of air, and protection from extremes and alternations of temperature, and moisture and dryness, as met with in the weather of tropical cli-

mates. Timber is destroyed by contact with slaked lime; it should not, therefore, be placed without protection in concrete or mortar. Lime, when dry, is not prejudicial; it protects the wood from worms.

209. Timber should be selected with reference to the purpose for which it is required; an inferior timber may be sufficiently durable where there is no exposure to the weather. Timber kept constantly wet is softened and weakened, but does not necessarily decay; certain woods are very durable under water, notably elm, beech, and seemul. When to be freely exposed to the severe atmospheric influences of the tropics, or to alternations of wet and dryness, only the most durable kinds of timber should be selected, and these should be guarded by proper precautions. For purposes of shipbuilding, the committee of Lloyds estimated the durability of several kinds of timber; this varied from twelve years for teak, British oak, saul, &c., to four years in the case of hemlock pine (North American). In France whole lines of injected fir poles are found in a good state of preservation fifteen or sixteen years after erection; but if not properly injected, they decay in five or six years; unprepared wood has a durability inferior to this. In America the poles are tarred at the base to 1 foot above ground. Their durability is—for cedar, fifteen to twenty years; chesnut, ten to fifteen; and oak, eight to ten. Good surface protection would increase this durability considerably. In India, the posts being charred and tarred at the base, if of iron-wood, or teak, last fifteen to twenty years; but if this wood be young, it is unserviceable after five or six years. Pine in large logs, as lower masts at river crossings, are tarred all over and charred at the base; they remain serviceable for five years. They are then decayed at the head, and the cross-trees and cap become dangerously loose; the buried portion remains quite sound if protected from insects by being placed below flood level. The durability of such masts might be increased by improved surface protection, regularly renewed, and by a portion of the top end of the spar being rejected, so as to ensure the top of the mast being of durable wood; the thinning of the head of the mast is also prejudicial to durability. Kandeb spars, 50 to 60 feet long, charred at the base only, are very durable, being found perfectly preserved after eight years' exposure in India.

210. Woods having the fibres straightest, least interwoven with the medullary rays and interrupted by knots, are most elastic, suffer least by warping, and split most economically; those in which the fibres are crossed and interlaced are tougher and stiffer; lignum vitæ owes its resistance to splitting to the latter cause. Most woods split more economically from the small end than from the butt of the tree. The tenacity of timber with the grain depends on that of the woody fibres, the

tenacity across the grain depends chiefly on lateral adhesion between the fibres; the tenacity with the fibres is generally greatest in timber having straight and distinctly marked grain, it is diminished by continued saturation with water, and by steaming and boiling. The tenacity across the grain is always much less than with the grain, it is diminished by wetting the timber; in pine wood this tenacity is very small as compared with that of leaf wood. The proportionate tenacities with and across the grain, ascertained by experiment is, in pine wood 1 : 20 to 1 : 10; in leaf wood 1 : 6 to 1 : 4 and upwards. The resistance to shearing with the grain—*i.e.*, by sliding of the fibres on each other—is the same, or nearly the same, as the tenacity across the grain. The resistance to shearing across the grain of English oak treenails has been found by Mr. Parsons to be 4000 lbs. per square inch of section, the planks connected having a thickness equal to at least three times the diameter of the treenail. Resistance to crushing along the grain is nearly twice as great for dry as for green timber of the same kind; in dry timber this resistance is generally from one-half to two-thirds the tenacity. Timber is more compressible and weaker across than with the grain. Many kinds of wood may be compressed to two-thirds or three-fourths their original volume, the compression being applied on all sides and across the fibres; this is done in driving treenails—they are driven into the work through an iron ring which compresses them. The resistance to cross-breaking (as in beams) is generally a little less than the tenacity. The following table contains the most important data for several woods in common use (Rankine)—

	R. to Crushing.	Tenacity.	M. of Elasticity.
Ash,	9,000	17,000	1,600,000
Bamboo,		6,300	
Beech,	9,360	11,500	1,350,000
Elm,	10,300	14,000	700,000 to 1,340,000
Fir, Red Pine,	5,375 to 6,200	12,000 to 14,000	1,460,000 to 1,900,000
„ Larch,	5,570	9,000 to 10,000	900,000 to 1,360,000
Oak, European,	10,000	10,000 to 19,800	1,200,000 to 1,750,000
„ American,	6,000	10,250	2,150,000
Teak, Indian,	12,000	15,000	2,400,000

The constants of transverse strength (Paragraph 144) are as follows, in pounds—

Ash,	666 to 777
Beech,	500 to 666
Elm,	333 to 540
Fir, Red Pine,	394 to 530
„ Larch,	277 to 556
Oak, European,	555 to 755
„ American,	588
Saul,	900 to 1,150
Teak, Indian,	666 to 1,055

211. The factor of safety in various actual structures in carpentry varies from 4 to 14, and is on an average 4 to 5 for a dead load, and 8 to 10 for a live load. In practice the load on timber is limited to 1000 lbs. on the square inch. From the above data the resilience may be calculated by the formula given in Paragraph 57.

212. Timbers are joined together by means of joints and fastenings of different kinds, chosen with regard to the relative positions of the pieces and the direction of the forces acting between them at the joint. Fastenings are classed according to the stress to which they are exposed—

1. Those exposed principally to shearing and bending, as wooden and metallic pins, including treenails, nails, screws, and bolts.

2. Those exposed principally to tension—viz., straps and tie bars; a band of wire used to bind timbers together forms a strap. Iron stirrups are included in this class.

3. Sockets.

Nails are made of wrought iron, cast iron, and malleable iron by hand and by machinery; hand-made nails are stronger than machine-made. A nail driven across the grain holds twice as firmly as one driven with the grain. Mr. Bevan's experiments shew that the force required to draw a nail from a given kind of timber varies nearly as the cube of the square root of the depth to which driven, and that it increases with the diameter, the law of increase not having been expressed. The force required to draw nails differs with the kind of timber; the results of Mr. Bevan's experiments on the force required to draw a sixpenny nail, seventy-three to the pound, driven one inch into different kinds of wood, were as follows—

	Across the Grain.	With the Grain.
Deal,	187 lbs.	87 lbs.
Oak,	507 „	
Elm,	327 „	257 „
Beech,	667 „	

The forces required to draw asunder a pair of planks joined by two nails, of seventy-three to the pound, were—

Deal, $\frac{7}{8}$ inch thick,	. . . .	712 lbs.
Oak, 1 " "	. . . .	1,009 "
Ash, 1 " "	. . . .	1,420 "

The nails for fastening planks to beams are usually from two to two and a half times the thickness of the planks. A hole should be bored to receive a nail to prevent the wood being split. The holding power of screw nails, or wood screws, is probably nearly proportional to the product of the diameter of the screw, and of the depth to which it is screwed into the wood; it is roughly three times the holding force of a nail. In screwing two pieces of wood together the screw should be free in the upper piece. Screws are made in sizes from half-an-inch to six inches in length; there are from twelve to thirty different numbers in each size, representing different thickness. The threads of bolts are usually made to a standard gauge, called Whitworth's gauge; the proportions are nearly as follows: depth of thread one-tenth, and pitch one-fifth, of internal diameter. Bolts are named by the shape of the head and neck, as cheese round neck, hexagon round neck, &c. Bolts are usually secured by nuts; when they have to be often removed they may be secured by a key or wedge driven into an oblong hole in one of their ends. Square bolts should be preferred, but cylindrical are the commoner, round holes being easier to cut. Timber should be protected by washers against the crushing action of bolt heads, nuts, and keys; it is evident the wood will be crushed before the bolt is strained to its breaking strain, unless the area of each washer bears at least the same proportion to the sectional area of the bolt as the tenacity of the bolt bears to the resistance of the timber to crushing. This proportion is 12 for fir, $6\frac{1}{2}$ for oak, and $5\frac{1}{2}$ for teak, these proportions being the lowest admissible in practice. When a bolt is placed obliquely to the direction of the timber, the timber may either be notched, so as to present a surface for the washer perpendicular to the bolt, or a bevelled cast-iron washer may be applied one of whose surfaces fits a notch made in the wood while the other surface is perpendicular to the axis of the bolt; the latter should be preferred generally, and a notch should never be cut on the stretched side of a beam. In driving wedges and joggles care should be taken to draw the joint well together without straining it; these are sometimes driven too tightly, by which the joint is weakened. Of European woods, elm is considered, on account of its toughness, to bear the driving of bolts and nails the best. Straps are used almost in

the same manner as bolts; they have the advantage over bolts of not requiring so much wood to be cut away; their breadth ranges usually from four to eight times their thickness. When practicable, straps to entirely surround timber may be made continuous, and driven on from one end; when not continuous, they may be bolted on by eyes or holes in the ends of the strap, in which case the strap should be widened or thickened at the eye, to give it the same strength there as elsewhere. A strap may have screws cut on its ends, a cross piece being placed over these and fastened with nuts. A band of wire (Nos. 8 to 12) forms an excellent strap for some purposes, but the wire should be payed on with a mallet or lever, and hammered close as put on; or it may be keyed tight with wedges. A stirrup is a kind of strap of the shape its name indicates; it is commonly welded into one piece with a suspending rod or stay. Sockets are made to fit the ends of pieces of timber; they should be of cast iron when they have to bear thrust only, of stout wrought-iron plates when they have to resist tension.

213. Timbers are said to be joined sideways, perpendicularly, endways, or obliquely, according to the direction of the fibres of the two pieces joined relative to each other. In jointing and fastening timbers, the following principles should be adhered to:—

1. Weaken the timbers joined as little as possible;
2. Place the abutting surfaces of the joint perpendicular to the pressure to be transmitted;
3. Proportion the areas of abutting surfaces to the pressure to be transmitted that the timber may be safe against injury; and
4. Fit each pair of such surfaces accurately, in order to distribute the stress as much and as uniformly as possible.
5. So proportion fastenings as to make them equal in strength to the timbers they connect; and,
6. So place them that there shall be no danger of them crushing or shearing their way through the timber.

Joints are classed as follows:—1. Joints for lengthening ties—*i.e.*, timbers subjected to equal and opposite forces applied to their ends and acting from each other; 2. joints for lengthening struts—*i.e.*, timbers subjected to equal and opposite forces applied to their ends and acting towards each other; 3. joints for lengthening beams; 4. joints for supporting beams on beams; 5. joints for supporting beams on posts; 6. joints for connecting struts and ties.

214. LENGTHENING TIES or timbers subjected to tension in the direction of their length, is performed by fishing or scarfing. In a fished joint the two pieces of timber abut end to end, and plates of iron or pieces of wood are bolted on to connect them; in a scarf, the pieces of timber joined overlap each other for some

distance. Fig. 39 represents a fished joint; in this kind of joint the fish pieces should have a total sectional area equal to that of the tie, but if of iron, allowance should be made for the greater tenacity. The fish pieces may have plane surfaces next the tie (plane

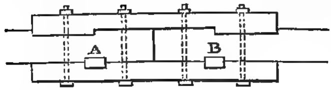


Fig. 39.

fished joint), or they may be connected to the parts of the tie by indents, or keys, or joggles of hard wood, A and B, as shewn in the figure. The effective area of the tie is diminished by the bolt holes, and by cutting the indents and key-seats when these are used. Keys and indents should be placed at a sufficient distance from the ends of the fish-plates and parts of the tie, to resist the tendency to shear off layers of the timber, and the area of their abutting surfaces should be sufficient to resist safely the greatest tension to be exerted along the tie. The bolts should have a joint sectional area at least one-fifth the area of the tie after cutting the bolt holes; they should be square rather than round in section, and should be so distributed and placed at such distances from the ends of the two parts of the tie, that the joint area of both sides of the layer of fibres which must be sheared out of one piece of the tie before the bolts can be torn out, shall be as much greater than the effective area of the tie as the tenacity of the wood is greater than its resistance to shearing. Fig. 40 is a joint scarfed and fished with iron

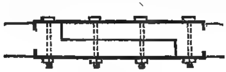


Fig. 40.

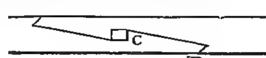


Fig. 41.

plates indented. Fig. 41 is a joint scarfed only; this joint holds without bolts or straps; a key of hard wood, *c*, of a depth one-third that of the tie, is driven in to tighten the joint moderately; this joint without fish-plates has only one-third the strength of the solid timber tie. Fig. 42 is a scarf joint with two keys; it is superior to 41 and easier to make sound. The proportion the length

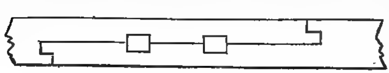


Fig. 42.

of a scarf should bear to the depth of the tie is given by Tredgold:—For leaf wood without bolts 6, with bolts 3, with bolts and indents 2; these figures being doubled for pine wood. The examples given are the simplest of the many ways of scarfing; these joints, however, are sufficient for purposes of telegraph

construction, and they are generally preferable to the more complicated joints. Timber is seldom submitted to tension in telegraph structures, iron ties being almost invariably used. Lengthening struts,—as this includes the case of a pillar or post as well as oblique timber, it is of frequent occurrence in telegraph structures. In this case the two pieces should abut against each other at a plane surface perpendicular to the direction of the thrust, the joint may be fished on all four sides (fig. 39), or the abutting ends may be enclosed in an iron socket. In lengthening a topmast or other timber which it is essential should not be much increased in girth by a joint, iron fish-plates may be used, and these may be let in or inlaid if necessary, or an iron socket may be driven on from one end. In the absence of fish-plates or bolts a spar may be scarfed, as in fig. 40, wire bands being substituted for the bolts and fish-plates to hold the joint together.

215. Lengthening beams.—Beams may be lengthened by fishing or scarfing, the following conditions being fulfilled:—1. The joint should be placed where the bending moment is small; 2. at the compressed side of the beam the two pieces should have a square abutment, oblique surfaces being avoided; 3. the surfaces of the scarf should be parallel to the direction of the load. Telegraph masts are struts with respect to their own weight, and should not therefore be joined by oblique surface joints, such as fig. 41; the bearing surfaces of the joint should be at right angles to the axis of the mast. A beam may generally best be supported on another beam by a shallow notch being cut on the lower side of the upper beam to fit on the lower one, but strict attention should be paid to the principle laid down in Paragraph 130. A mortise and tenon joint, or a shouldered tenon joint is used to connect beams when one beam meets another at right angles; the shouldered tenon, which is the best joint in this case, is shewn in fig. 43. Post and beam joints.—To support the end of a horizontal beam at the side of a post, a shouldered tenon is used; where it would not weaken the work too much, and in small work generally, a common mortise and tenon joint is used, fig. 44; the projection on the end of the beam *a* is called the *tenon*, and the cavity cut in the post to receive it the *mortise*, the timber from which the tenon projects is called the shoulder of the tenon. The shoulder of the tenon and the mortise should be cut to exactly the same depth. The joint may be keyed, or a pin may be driven through the tenon to prevent it drawing from the

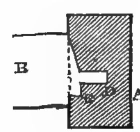


Fig. 43.

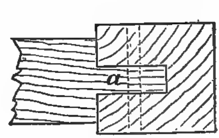


Fig. 44.

mortise. The tenon is usually cut to one-third of the wood. Instead of one tenon, two tenons and mortises are usually cut in large work. The mortise and tenon weaken the timber too much to be applicable when the beam or post has to resist a considerable load; it is applicable to small or temporary work, but more properly belongs to joinery, and its misuse in carpentry should be avoided. In carpentry the shouldered tenon, fig. 43, is used; B is the beam, A a section of the post, C is the shoulder of the tenon which bears the load; it penetrates the post at C for about one-sixth of the depth of the beam; the depth of the tenon and shoulder is two-thirds to three-fourths that of the beam, the width of the tenon proper is about one-sixth that of the beam, and its length is double its depth; its use is to prevent the shoulder C shifting from its seat. The tenon proper should be in this case at right angles to the direction shewn in the figure—*i.e.*, to the shoulder C; the figure represents a joint between two beams. In the case of a beam resting on the top of a post or of a post standing on a beam, a small tenon on the post may be fitted into a mortise in the beam, or either of the joints A, E, fig. 45, may be used; the post is let into a notch cut in the beam, the notch is divided into two parts by a bridle (shewn by the dotted lines FG, CD) about one-fifth the width of the beam, this bridle fits into a groove of the same shape and size cut in the top or bottom (as the case may be) of the post.

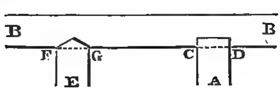


Fig. 45

216. A STRUT MEETING A POST, BEAM, OR TIE OBLIQUELY,—the timbers are joined by bridle and groove, as in the case of post and beam described above, or by a mortise and tenon. In fig. 46 the strut A is notched into the tie B; the notch has one plane surface, CD, bisecting the obtuse angle, and the other plane surface bisecting the acute angle the timbers make with each other; a tenon F one-fifth the breadth of the strut is shewn by the dotted lines. In fig. 47 the

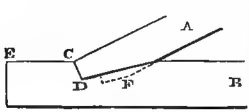


Fig. 46.

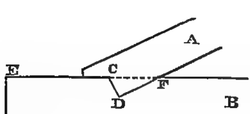


Fig. 47.

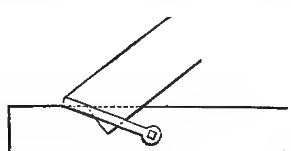


Fig. 48.

notch is cut with one surface, CD, perpendicular to the direction of the strut, a bridle being left on the tie or beam, and a groove cut in the strut to receive it; the bridle, CDF, is one-fifth the depth of the tie. A stirrup may be applied, as in fig. 48, or bolts may be used *placed obliquely to the tie, post, or beam.* This case is common in telegraph construction, and much unnecessary objection has been made to cutting the post, or making bolt holes through it; as the surfaces of the joint are oblique to the axis of the post there is some loss of strength, but it should be remarked, that the notch is cut on the compressed side, and that with a stirrup the bolt hole passes through the neutral axis of the section; but in telegraph work the joint often occurs where the bending moment is greatest.

217. The application of the preceding principles to telegraph construction will be generally evident. A line constructed for a temporary purpose may from necessity be placed on inferior kinds of wood, young, green, and felled at an improper season; but even in this case it is apparent, by adopting certain precautions, the durability of such timber may be increased, and these precautions become of greater importance when there is the possibility of the line being required to stand longer than could be anticipated at the time of its erection. The conditions to which telegraph poles are exposed in tropical countries are very destructive to timber, as already stated; alternations of fierce heat, high winds, abundant rain and dew, render it necessary to adopt every possible precaution to protect the wood. Hard woods needing little or no protection from insects should be protected by a good surface protector, renewed as requisite; tar unmixed with oil is too thick, and does not penetrate the wood; if tar be used it should be mixed with oil, and used hot. Coniferous wood, or other wood liable to be attacked by insects and to split from exposure, should not only be well painted with a surface protector, renewed from time to time, but this wood should be also injected or saturated superficially with creosote; if merely applied to the surface, the creosote should be applied hot. All timber should, as far as possible, be seasoned; and surface protection should not be applied to green wood. Posts erected green should stand at least one year before a surface protector is applied, and this should then be applied during hot dry weather. Unseasoned wood is much improved by a fortnight's soaking (first stage of water-seasoning), and this should be applied whenever practicable in the absence of the means of seasoning the wood more perfectly. For a hardwood line great care should be exercised in choosing mature wood, young trees of all kinds are to be avoided as being very perishable. The extra durability of the butt of the tree should

be kept in view, and in sawn timber posts, the butt-end should be marked by the sawyer that it may be put in the ground. Where admissible, bolts and straps should be preferred to wood-screws and nails; in jointing frames, as in trussed posts, &c., iron sockets, stirrups, and fish-plates should be used; and ties should, as a rule, be of iron wire or rod. In making joints the models given should be applied, and the principles stated should be kept in view in applying them. A telegraph pole may be considered as a post or strut subjected to vertical pressure, and as a beam when subjected to pressure acting obliquely; the poles in a straight line are normally struts, those at angles are normally beams and struts. When poles break it is due generally to transverse strain, and the post may be considered as a beam fixed at one end; but posts loaded much vertically, as when lengthened considerably, or when supporting long spans or many wires, must be considered also as struts. Timber in which the length exceeds 100 times the diameter bends by its own weight.

Division II.—Masts.

218. Masts may be classed as standing and compound; the former are in one piece fixed in or on the ground, the latter consist each of a standing mast supporting one or more running masts to give increased height. Both running and standing masts may be either made from a single tree or built of several pieces of wood.

219. The wood commonly used for ships' masts is pine; for telegraph masts light elastic wood should generally be preferred, but these qualities are not so essential as in wood for ships' masts. Timber should as a rule be obtained locally—*i.e.*, as near as possible to the site of the proposed crossing, inquiry being instituted for any timber likely to suit the purpose; in no case should foreign timber be imported until indigenous timber has been well sought after. Having found timber of suitable quality and proportions, a slice should be cut off each end to examine the soundness and the quantity of heart-wood; it should also be examined for faults by bending (Paragraph 203).

220. If the wood be purchased in the market it will probably be shaped, its section being an octagon; if the log be obtained from the forest it may be shaped, or if regular in shape it may be used round. The advantages of using the log round are saving of labour and greater strength; the disadvantages are the difficulty of preventing splitting in drying, and rapid decay of the sap-wood may endanger the safety of the mast by the loosening of fastenings. If the log is to be seasoned slowly it is probably better to shape it;

if the sap-wood can be injected, or water-seasoning is to be applied, it is probably better to use the log round. No difficulty need be experienced in injecting with sulphate of copper on the spot; a simple apparatus may be devised for the purpose, and prepared beforehand. If the tree is to be used round it should be injected or soaked, and then barked and smoothed with the plane, being suffered to dry as slowly as circumstances will permit, and sheltered from exposure to sun and wind as long as possible. If to be shaped the log should be placed on blocks or thawts; ii crooked, the concave side should be squared first, the sides are then cut perpendicular to this surface. The stick is reduced to a rectangular prism, it is then reduced to an octagonal prism by removal of the angles; in reducing, the lines should be drawn on the cut surfaces and the ends, and care should be taken by frequent neasurement that the surfaces make the required angles with each other. When the stick is reduced, as above, it may be considered shaped, and is ready to receive fittings, such as stay-hoops, brackets, &c.

221. The most economical proportions for a simple mast are one inch diameter at base for each three feet of length, the diameter at point of application of strain to be two-thirds that at base.

222. The efficiency of stays to masts is calculated as for ordinary poles. Care is necessary to prevent the stay hoops from slipping down as the mast shrinks and its outer wood decays; this accident is guarded against by the mast being shaped with a prominent ring of wood for each hoop to rest on, the hoops may be let into the mast, or they may be supported by bolts; they should in all cases be discontinuous and closed by bolts passed through ears; the bolts serve as attachments for the stays, and are used to tighten the clamp from time to time. The first-named arrangement is preferred when the mast is shaped; nails and staples wear loose, square-headed wood screws are more reliable. As a rule, masts should be inserted in the ground for from one-tenth to one-eighth of their length. If a mast be erected on a low bank periodically flooded, it is not liable to be attacked by white ants or other destructive insects which may be indigenous to the country; if the bank be high, the base of the mast may require to be carefully protected, particularly if the wood be of a kind very liable to be attacked by insects. In the latter case, the butt of the stick should be well roasted and painted while hot, either with creosote or a mixture of oil and tar; it should then be covered with sheet copper, Muntz metal, or zinc, fixed on with copper, brass, or zinc nails respectively, to a foot or more above the earth-line. Zinc oxidises rapidly on the

surface next the tar; zinc of the gauge usually employed is destroyed by this cause in three to four years, and should not be used for masts required to last longer. If the wood has been seasoned, a surface protector should be carefully applied over the whole surface of the mast; two or more coats of oil and lead paint, or of oil and tar, may be applied before erection, and extended to the inner surfaces of all joints; or the joints may be made water-tight with white lead, in order to exclude moisture. The top of the mast should be furnished in every case with a rain cap, and this should be applied even to the heads of lower masts. To hinder the drying up of the wood in tropical climates, a good plan is to bore a hole in the top of the mast with an auger, for some distance boring out the pith; this hole should be kept well supplied with oil, being fitted with a peg to keep out rain and hinder evaporation; the oil is absorbed by the wood, and the mast lasts much longer, and does not become so brittle as when this precaution is neglected.

223. When a mast is required of such a size, either as regards length or thickness, or both, that no single trunk would furnish a stick of the required size, or when a mast is to be built entirely of heart-wood, no trunk supplying this in sufficient quantity, the mast is built. A built mast is composed entirely of the strongest and most durable part of the trees, and is therefore justly esteemed above a single-stick mast; there is less risk of unsoundness in the built mast, and the hoops used to bind it render it denser and stronger; but to build a mast requires more knowledge and skill to ensure success than to shape a single stick. If a standing mast is to be built of two or more pieces of timber joined in the direction of their length, the joints should be chosen as directed in Paragraphs 216 and 217, and the mast should be stayed at the joint. The joint may be scarfed or fished—a socket may be fitted on the end of each log, and the logs bolted together by the socket flanges, this is useful when a mast is to be erected in pieces; straps or hoops, or one wide hoop driven on from one end may be employed, but as the outer wood deteriorates, bolts through the heart should be used as a rule. In connecting thick timbers, iron or hardwood dowels may be employed; the jointing employed in constructing the masting shears (described by Mr. Glyn) built by the late Oliver Lang, Esq., at Woolwich dockyard, furnish an example of their employment. The spars for the shears and sprits are 26 and 24 inches in diameter, and 132 and 136 feet long respectively, and octagonal in section; plates of wrought iron $1\frac{1}{2}$ inch thick were inserted in the abutting end of each spar, four wrought-iron dowels, 2 feet long and 4 inches thick, pass through the octagonal

plates, a central plate, $1\frac{3}{8}$ inch thick, is placed between the abutting surfaces—its edge is notched to receive the fish-plates—this plate prevents twisting at the joint. The joint is held together by long iron fish-plates or splints, let in flush on each face of the prism and bolted by through bolts, wrought-iron hoops are driven over the splints, and a thick broad hoop is driven over the edge of the centre plate. The dowels give additional stiffness, and the joint is calculated to resist thrust well; it is suited to the case of a telegraph mast, particularly when two sticks are required to be joined endwise without sacrifice of height; the joint should be invariably protected against transverse stress by stays. Such a joint requires to be made with great care to fit the parts together accurately, and it would be better in hard wood than in pine.

224. The principle to be kept in view in building a mast to gain increased diameter, is to so connect the pieces of which the mast is composed that they may resist transverse stress, not as several pieces acting together, but as one piece (Paragraph 131). If several pieces of wood be placed together and be free to slide on each other, the combination will be more elastic, but weaker, than a single piece of wood of the same dimensions. If the pieces be indented into each other or keyed, it is evident the component parts of the compound log must bend together and act as one piece, provided the indents or key-seats be deep enough to resist the tendency to shear off layers of fibres. A beam to be supported at both ends, and loaded uniformly or in the centre, should be built symmetrically from the centre; if it is to be bent in one direction only, it may be built as in fig. 51, which represents a beam to be loaded vertically, the abutting surfaces of the upper piece face outwards. If a bar be liable to be bent in every direction, as in the case of a mast, the indents or keys should be the same in both pieces, as shewn in figs. 49 and 50. If joggles or keys be used, they should be placed with their fibres at right angles to those of the beam, and in the direction of the beam's depth; if they be made of iron, or wood much harder than that joined, they are more liable to work loose and damage the timber, than if of a material more nearly approximating in hardness to the timber they are inserted in. Neither indents, bolts, nor keys are placed where the shearing stress vanishes, nor where the bending moment is a maximum. According to Tredgold, the joint depth of all the keys should be somewhat

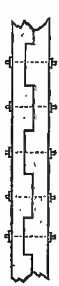


Fig. 49.

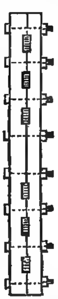


Fig. 50.

greater than once and a third the depth of the beam, and if of hard wood their width should be about twice their thickness. According to Duhamel, the joint depth of the indents should not be less than two-thirds the depth of the combination.


Fig. 51.

Figs. 49, 50, and 51 illustrate the principles on which beams and masts are built, but in the case of the latter, practice varies and differs more or less from the above models. Figs. 52 and 53 illustrate modes of building masts employed in practice. Fig. 52 A is a mode used in the French navy; a feather in one piece is let into a groove in the other; to prevent sliding when resisting stress in the plane of the paper the bolts are alone to be depended upon, and these ultimately wear loose in consequence of the vibration and the softness of the wood.

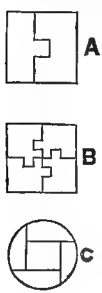


Fig. 52.

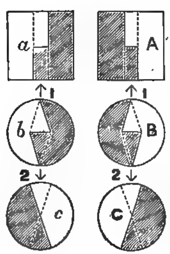


Fig. 53.

In hard wood the bolts would not so readily become loose, but as the sliding is not prevented by abutting surfaces, this joint is not recommended. B and C, fig. 52, are other modes of building; in C keys may be used to prevent sliding; a mast may also be built by planting logs on a central log shaped to a polygonal prism, the whole being connected by indents or joggles to prevent sliding, and hooped. More perfect modes of building are shewn in fig. 53; the sections *a*, *b*, and *c* alternate with A, B, and C respectively, at equal distances along the length of the mast; it is evident sliding is prevented by these modes of joining, they are on the same principle as figs. 49 and 51. A*a* is a good model, it is less dependent on accurate fitting, and less likely to become loose, if the wood should warp, than figs. 49 and 51. The practice in Her Majesty's dockyards is shewn in fig. 53 B*b*; it is evident on inspection of the figures, in resisting stress in the direction of the arrows the greatest strain on the abutting surfaces is where these surfaces are weakest—viz., at the points 1 and 2, and where the stress is very slight (viz., at the centre) the abutting surfaces are most extensive; C*c* is evidently a more rational form, but B has certain practical advantages when applied to ships' masts; the outside seam is straight, it therefore looks fairer, and water cannot lodge in it; this form draws together well when hooped, the hearts of great trunks

being softer than the outer rings: the soft heart in this form of joint is well exposed to compression by hooping, the compression rendering the hooped-built mast stronger than a single piece of the same dimensions—this form is also calculated to resist torsion. Of the above models, fig. 53 A*a* is the plainest; it is the easiest to make well, and for jointing rectangular logs should be as a rule preferred; B*b* is a model in use for ships' masts, but as telegraph masts do not have to resist torsion, and are sometimes of hard wood, which cannot be much compressed by hooping, C*c* seems better suited to the necessities of the case; it would not hoop so well, and more wood is sacrificed than in B*b*, but the joint is easier to make well; there is a larger opening in C*c*, in which moisture might enter, but the surface of the joint is less, and there is less danger of water lodging in the interior than in B*b*. In building masts after these models the pieces should be fitted as accurately as possible, the plane being used in finishing the surfaces; when put together the seam should not be quite close at first, it should be closed by the hooping, the hoops being driven hard, and a considerable interval being allowed to elapse between each spell. In adding pieces in the direction of the length, when building a mast in length as well as diameter, these pieces should break joint with each other. The proportions of built masts are the same as those indicated already for single-stick masts (Paragraph 221).

225. When great height is required (above about 70 feet), it is usual to employ a standing mast carrying a running mast, and the compound mast is then constructed after the model of a ship's mast modified to suit the simpler case of a telegraph mast, which not being required to carry sails, &c., does not need such numerous and complicated fittings. The parts of a ship's mast, their functions and relative positions, are described below. The line on the mast marking the line of the deck is the *partners*; at this place the mast has its greatest or *given* diameter, which is referred to as the diameter of the mast; the diameter of a telegraph mast is its diameter at the ground line. The end of the mast resting on the keel of the ship is termed the *heel*, and the portion between the heel and the partners is termed the *housing*. From the partners, measuring in a direction from the heel, the mast is divided by imaginary lines into four parts, the points of division being termed the quarters; one of the four parts forms the head, which extends from the third quarter to the end of the stick. As the housing is commonly from a quarter to nearly one-third of the total length of the mast, it follows the length of the mast-head is from three-sixteenths to one-sixth the total length of the standing mast. For example, in a standing

mast having 110 feet extreme length, about 19 feet would be head and 29 feet housing, the height gained above deck would thus be 62 feet only. A similar telegraph mast would be buried only 10 to 12 feet, and would have therefore additional height for the same extreme length. Fig. 54 represents the head of a standing mast and the heel of a running mast (termed the topmast) fitted together:—*f* the standing mast has oaken cheeks *e*, fastened to the mast by five through bolts, and by either two square coaks formed from the mast, or by circular coaks; the lower portions are secured by a hoop or hoops. The diameter of the standing mast at the upper line of the oak cheeks, termed the hounds, is three-fourths the given diameter; the heading is square in section, and tapers from three-fourths to five-eighths of the given diameter. *d* the trestle trees rest on the cheeks, which project therefore from the mast at the upper part, at least half the width of the trestle trees. The trestle trees are made equal in depth to half the given diameter of the mast, and in breadth to half their depth. In ships' masts the length of the trestle trees is regulated by the breadth of top required fore and aft, but in telegraph masts they should only be long enough to carry the topmast, and to allow enough wood to carry the necessary bolts and fastenings safely; they are rounded off at the lower corners, as shewn in the figure. The cross-trees *ab*, are made in length the breadth of top required, but in telegraph masts they need only be made to project beyond the trestle trees a distance equal to their width; they are the same breadth as the trestle trees, and in thickness two-thirds their depth; they are notched on the trestle trees by scores about an inch deep cut on the trestle trees, and half this depth on the under side of the cross-trees; these notches being placed together, saucer-headed bolts are put through at the junction, and nutted at the under

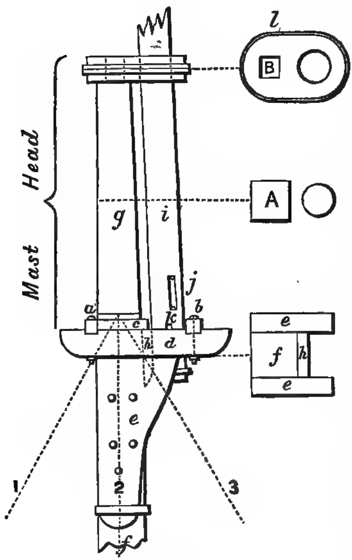


Fig. 54.

side of the trestle trees. Chocks *h, h,* are put on fore and aft of the mast in ships' masts, but one chock, or a third cross-tree, to separate the standing and running masts is all that is necessary in telegraph masts. Blocks termed bolsters, *c*, are bolted to the mast, their upper outer edge is rounded off; the stays (shrouds) are placed round the mast-head, and rest on the bolsters, which are curved and padded or plated with metal to receive them, the bolsters protect the stays and trestle trees from injury by contact with each other. When the shrouds are of hempen rope, the bolsters are covered with tarred canvas or leather; but when the shrouds are of iron, iron plate is used over the bolsters; on telegraph masts hardwood bolsters or a covering of metal may be used; there is less wear on the bolsters than in a ship's mast. Telegraph masts should be stayed in the same manner; the stays are usually used in sets of four, they should be well spread, and disposed so as to be equidistant from each other, and also from the mast. In ships' masts the cross-trees are frequently continued for some distance beyond the trestle trees, and are made to serve as strut braces to stiffen the running mast; in telegraph masts it is evident the trestle trees might also be lengthened and employed as struts; but this can seldom be necessary as there is usually no limitation either to the spread or number of the stays. When, however, this trussing becomes necessary or is deemed expedient, the ties are connected to the standing mast by an iron hoop or chain necklace let into the lower mast below the cheeks; this hoop or chain is provided with tie shackles, and should have one or more openings with ears through which a bolt or bolts are passed to draw it close to the mast. The mast-head is square in section, a square tenon being cut for the cap. The cap *l* may be made of wood or of iron; the latter is probably best suited to telegraph masts, iron caps being simpler than those of wood; the wood employed in the merchant service is usually African oak. The cap is in width twice, and in thickness five-sixths the diameter of the topmast, the ends are rounded as shewn; the holes are set off so that the substance of the wood left between the holes equals half the taper of the mast-head and the thickness of the chock between the trestle trees; the wood left between the round hole and the end is equal in width to two-thirds the depth of the cap; the width between the square hole and the after end of the cap is equal to the depth of the cap; the round hole is one inch larger than the diameter of the topmast to pass through it, seven-eighths of this is to allow for a leather padding and one-eighth for play. The cap is generally reduced in thickness one-twelfth on the edge for the gain in lightness. It is surrounded by an iron hoop, generally about one-third its depth and one

quarter to five-eighths of an inch thick, according to the size of the cap; horizontal strengthening bolts are driven through the cap and clenched. In setting the cap on the tenon of the mast-head, the square hole is cut taper, and it should not go down to the shoulder of the tenon within one and a half inch to allow for shrinking. Two iron plates should be screwed on the trestle trees for the fid *k* to rest on; a ring-bolt is bolted to the cap to carry a block used in raising and lowering the topmast, but in telegraph masts a rope sling put round the cap when required is to be preferred.

226. Topmasts have their given diameter at the standing mast cap, from this to the heel they are parallel; the heeling is two to two and a half diameters long; if it is too small to fill the hole in the trestle trees, filling must be applied to the hole, allowing only a quarter of an inch for play. A hole for the fid *k*, figs. 54 and 55, is cut through the axis of the mast, the lower edge of the fid-hole being made at a distance from the hoop 1 2 3, fig. 55, one inch greater than the depth of the trestle trees, the inch being allowed for the iron plates placed on the trestle trees for the fid to rest on. There is often want of skill in working telegraph masts, and they are more likely to stick in the trees than ships' masts, being seldom run; hence there is a liability to run the topmast heel out of the trees: the author knows of two instances in which topmasts were shot over the caps, fell to the ground, and were broken. The best mode of preventing this accident is to have projections forged on the ring 1 2 3, fig. 55, to prevent it passing through the trees. Fids are mostly of iron, their length is usually one and a half the given diameter of the lower mast, their depth one-third the diameter of the topmast, and their width two-thirds their depth. A sheave *s*, fig. 55, is placed above the fid-hole, the groove being cut from the centre line of the surface 3 to the central line of the corresponding surface on the opposite side. Fig. 56 shews the head and stops of a topmast, the shoulder *c* forms the stops, the head above the stops is square in section. The proportions of the cap, &c., are the same as for standing masts, but the stops of the topmast must not be too large to pass through the lower mast cap; and the diameter at the hounds

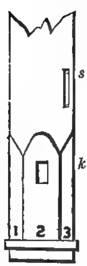


Fig. 55.

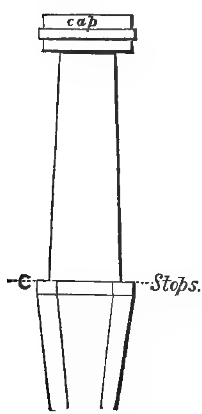


Fig. 56.

is $\frac{9}{13}$ and at the head $\frac{6}{11}$, of the given diameter, which is about $\frac{2}{3}$ that of the standing mast. Bolsters are used as for lower masts, and topmasts are stayed in the manner described for standing masts. The running mast, which is supported by the topmast, is termed the topgallant-mast, and the mast above this is the royal mast; the second and third named are usually in one piece, the royal being only a continuation of the topgallant-mast; in this case the cap, trestle trees, &c., are of course unnecessary to connect these two masts. The heeling of the topgallant-mast is formed like that of the topmast; the lower edge of the fid-hole is one diameter and one inch from the heel, its depth is half the diameter, and its width three quarters of its depth. A shoulder merely marks the termination of the topgallant-mast and the springing of the royal pole, the latter being usually short. On this shoulder the stays rest, a copper tube with a rim, fig. 57, being first let over the royal-mast to rest on this shoulder; the rim or flanch of this tube causes it to catch on the topmast cap and support the stays there when the topgallant-mast is lowered. The topgallant and royal-masts may be regarded as one-mast. The diameter of the topgallant-mast is greater usually than two-thirds of the topmast, the taper is the same as that given to topmasts. The height of a ship's masts is regulated by the extreme breadth of the ship, in order that the masts may be properly supported by the rigging; the confined area in which the mast has to be stayed also renders it necessary to brace it. In the case presented by a telegraph mast there is not the same limitation as to height; bracing may be employed, but staying is sufficient when only one running mast is employed, the commonest case in practice.

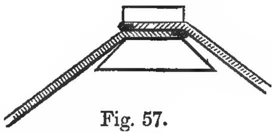


Fig. 57.

227. Two examples, shewing the height gained by ships' masts, are given below :—

EXAMPLE I.—Merchant vessel, 1563 tons. Breadth, 42 feet 6 inches—

	Length.	Head.	Diameter.
Mainmast, ...	101′ 6″	16′	32″
Topmast, ...	60′	8′ 6″	19″
Topgallant-mast, ...	34′	...	14″
Royal-mast, ...	22′ 6″	...	$8\frac{1}{2}$″
Totals, ...	218′	24′ 6″	...

In this example, from the extreme length must be deducted about 24 feet for housing, and 24 feet 6 inches for the heads; the height above the deck is thus about 170 feet.

EXAMPLE II.—Man-of-war, 120 guns—

	Length. Feet.	Diameter. Feet.
Mainmast,	119·66	3·33
Topmast,	68·08	1·71
Topgallant-mast,	34·41	·97
Totals,	222·15	...

From this total must be deducted about 35 feet for housing, and 30 feet for heads, giving 157 feet clear; this would be increased by the royal pole. In telegraph masts the loss of height by housing is only 10 or 12 feet; thus, a telegraph mast might be erected, after the model of ships' masts, to stand nearly 200 feet clear, without exceeding dimensions common to ships' masts. Col. Shaffner describes several high masts—one was composed of a standing mast 110 feet long, surmounted by four running masts, 70, 57, 43, and 27 feet respectively; the heel was not buried. The design was not, however, in several respects such as to be worthy of imitation; it is merely referred to as the height attained in practice. Sometimes masts simply stand on a platform, being held to prevent slipping by a suitable arrangement of timber; the platform distributes the pressure over the ground to which it is fixed by piles. In India a mast the base of which had been damaged by white ants, was rendered serviceable by placing a platform of timber under it in the manner described; and this mode of construction has advantages which may render it worthy of consideration under some circumstances, the principal being—the gain in height, the fact that a platform of teak may support a pine mast and protect it from white ants when the ravages of these are to be feared, and the foot of the mast is exposed for examination; but it is simpler and much cheaper, under ordinary circumstances, to place the mast in the ground, and the employment of the other mode must be regarded as exceptional. The rivers Luckya, Brahmapootra, Toongaboodra, and Gorai, in Lower Bengal, were crossed by compound masts; at the first three, the masts were each of two pieces, one standing and one running mast; the standing masts were 74 and 75 feet, the running

masts about 44 feet, in some cases less, and the masts complete stood somewhat over 100 feet clear.

228. In staying ships' masts the stays are placed above the bolsters in standing and topmasts, and on the shoulder between topgallant and royal-masts; collars, clamps, or hoops are not used; the stays are simply put round the masts, the latter being protected by the bolsters. It is evident the stays cannot tend to twist the mast, as they are free to move on it. Telegraph masts should have the stays placed as in ships' masts, on the bolsters; but if collars, clamps, or hoops be used, care should be taken they connect the stays and mast in such a manner that there be no strain on the mast tending to twist it. The stays of standing masts may be of oval-linked chain or of wire rope; the stays of running masts should be of wire rope. The lightest staying consistent with efficiency should be calculated for each case, due allowance being made for the leverage with which the load acts, and for the stays acting at an angle. The maximum transverse and vertical loads to be borne should be decided upon, and the strength of the structure in every part regulated accordingly. When topgallant-masts are not used, it is evident the staying of the topmast may be lighter, as it is not acted upon by the load with the same leverage. For example, if a mast to stand 100 feet clear to be stayed at 50 feet, is to resist a horizontal load of 500 lbs. applied at the top, then the load at 50 feet will be equal to 1000 lbs.; the stays, if placed at 45° with the mast, must offer a resistance of 3000 lbs; this multiplied by 4 as factor of safety, is 12,000 lbs., or upwards of 5 tons; oval-linked chain $\frac{7}{16}''$ in diameter would be about the strength required; if the stays could be attached higher they might be lighter. In the above example the resistance of the earth in which the mast is fixed is neglected; the stays alone are considered. If a second set of stays be applied nearer the load, the segment between the two sets of stays acts as a beam supported at both ends; in this case, if the upper part of the mast be strong enough to carry the load without the assistance of the longer stays, the lower stays should be calculated also to carry the load without the assistance of the upper ones, but the lower set of stays should be strong only in proportion to the topmast.

229. As the lowering of running masts is an expensive operation, not only by reason of the number of men required, but in the provision of heavy tackle liable to rapid deterioration, particularly when exposed to light and damp, and in the carriage of this tackle, masts should not be lowered, but means should be provided for readily climbing them. Blocks of wood nailed to the mast have been used, but these get loose and become unsafe, while

they injure the mast and afford no means of holding on by when ascending. Probably light iron ladders, made of wire or wire rope, fastened to the trestle trees and hanging perpendicularly from them, would best suit the purpose; the ladders should be fixed at their base, the lowest from the lower mast trestle trees may be fixed in the ground or to a projection from the mast for the purpose, the upper mast ladders might be fixed from trestle trees to trestle trees; they should allbe steadied by intermediate attachment to the mast. An excellent mode of climbing a mast is to have a block fixed at the top, with a light line reeved through it; this line is used to haul up a thicker line, by which a man may be hauled up; the ends of the permanent line should be tied to the mast high above ground until required. This is economical, efficient, and safe.

230. In putting on caps, trestle trees, and all similar fitting to masts, white lead should be freely used in the joints to exclude moisture; and tow and white lead, soft wooden wedges, or other suitable stuffing, should be used in the trestle trees and caps to diminish vibration.

231. The above description of a ship's mast is very general, and much is omitted which is proper to ships' masts only; ships' masts are varied according to the necessities of each case, the taste of the builder, &c.; but the description given contains all that is essential, and the proportions of the parts are those which experience has shewn to be best in practice. In constructing telegraph masts on the model of ships' masts, the great difference between the conditions must be kept in view to ensure economy. The ship's mast is stayed and worked in a very confined area, it is subject to the motion of the ship, it has to carry heavy yards, sails, and running rigging, and to resist the effort of the sails; the weight of the yards alone will be seen to be very great, when it is considered that the mainmast, described example I., p. 147, would carry the following yards:—

	Length.	Given Diameter.
Main-yard, ...	86′ 6″	22″
Topsail-yard, ...	70′	16″
Topgallant-yard, . . .	50	$11\frac{1}{2}$″
Royal-yard, ...	39′ 8″	$8\frac{1}{2}$″

To these yards must be added the studding-sail booms, the application of which has the effect of virtually lengthening the yard

from both arms, increasing greatly the weight to be carried; the yards, together with the enormous quantity of canvas, rope, &c., must bring great strain on the masts and standing-rigging when the ship is rocked by the waves. Telegraph masts are simply required to carry their own weight and the weight of the wires they support, they are stationary; the stays can have any desirable spread, and need not, therefore, be so strong or so numerous as the shrouds and stays of a ship's mast; the telegraph mast has to stand at its full height during the roughest weather, it should hence be stayed as high up as the position of the wires will permit; but the whole circumstances of each case being considered, it will be evident the strains to which a telegraph mast is subjected are trifling compared with those to which a ship's mast is liable. The telegraph mast should not be subjected to transverse strain by fixing the wires to the insulators; the wires should be strained from the ground and not against the top of the mast by the use of ratchet-drums or other similar contrivances attached high up the mast, and tall masts should not be used as angle posts. Telegraph masts, however, are more liable to deterioration from neglect of surface protection and staying, leading to loose fastenings, injury to and surface decay of the timber, &c.

232. Ships' masts are not erected vertical, but are set up to rake; telegraph masts should be erected so that a vertical line through the centre of gravity of the combination will pass through the centre of the base.

233. The advantages gained by using the running masts, rather than standing masts of increased height, are greater facility in erecting and in gaining access to the fittings at the summit by lowering the running masts; but it will be evident, on consideration, that a single standing mast of the requisite height is much more economical and efficient. Telegraph masts should not be lowered, and every care should be taken by efficient staying, that the mast is not subjected to transverse strain, and acts, as far as possible, as a pillar or strut; the single standing mast would resist the pressure in the direction of its axis, the compound mast carries the weight diagonally, and therefore at a disadvantage. The standing mast would be lighter than the compound mast; it would be more economical, requiring less timber and less labour, while, from the whole being joined more nearly into one piece, the vibration is less and the strength greater. There does not appear any reason why a wooden mast should not be erected in pieces, as is done in the case of structures of iron, the joints should, of course, be made, and the fastenings fitted in the first instance on the ground, each part should

be stayed as erected, and before another portion is hoisted; the weight of the pieces to be hoisted may be considerable, the strength of the tackle and temporary fittings should be proportioned accordingly; the maximum weight to be hoisted would seldom, in practice, exceed one ton. The masting shears already alluded to (Paragraph 223) present an instance of a very large standing mast—the mast was 134 feet long, 44 inches in diameter, and surmounted by a flag pole 44 feet long; it was built in the same manner as a ship's main standing mast. In compound masts, and exceptionally high built simple masts, the proportion of diameter at base to height is preserved; but it is evident the diameters at base and point of application of the load should not be as 3 : 2, as described for simple masts; as a general rule, in building a simple mast, the diameter at the first stay-hoop should be two-thirds that at the base, the diameter at the second stay-hoop two-thirds that at the first, and so on, each segment between two contiguous tiers of stays, or between the ground and the first hoop, should be proportioned as a simple pole; although, so long as the stays are efficient, the pole is not strained as a cantilever, the stays may become loose or be accidentally damaged, and this should be provided against when practicable.

234. The fact that these masts act as both pillars and beams must be kept in view in choosing the kind of joint to be used in building them. Compound telegraph masts are usually of two spars only; the faults to be particularly avoided in erecting and maintaining these masts appear to be the following :—Use of too light a topmast, weak stays not well attached to the mast, and placed below instead of above the bolsters, and neglect to stuff the holes in the trestle trees and cap to diminish them to fit the topmast. The relative merits of iron and wood for the construction of masts is discussed under the heading Iron Masts.

Section II.—*Earthwork.*

235. In telegraph engineering the necessity for extensive earthwork does not occur, but the small works required ought invariably to be of the best possible quality; hence the necessity for a knowledge of the principles on which the durability of such work depends, and the best mode of attaining the maximum durability in practice. Earthwork is of two kinds, excavation or cutting and filling or embankment; the term applies not only to such works in earth, commonly so called, but also to embankments made of broken stones and excavations in solid rock; in the present case, unless expressly stated, it is restricted to the first only, excavations in solid rock being treated separately.

236. The adhesion of earth is destroyed by moisture, exposure to the air, and changes of weather; it is not therefore relied on in embankments or cuttings, excepting for temporary purposes, as in the execution of excavation; it is due to adhesion that in most kinds of earth a freshly cut surface will stand with a vertical face for a certain depth below its upper edge; if it were not for this adhesion, holes could not be dug in the usual way with vertical sides. The depth to which earth will stand with a vertical face depends evidently on the relation between its adhesion and heaviness; it is increased by a certain degree of moisture, but diminished by excessive wetness. The greatest depth of temporary vertical face for several kinds of earth are as follows :—

Clean dry sand and gravel, . .	0
Moist sand and ordinary surface mould,	from 3 to 6 feet.
Clay (ordinary), . . .	„ 10 „ 16 „

It is evident holes cannot be safely dug in the soils named below the depths in the table, unless the sides be supported by timber or otherwise, or they be cut obliquely. As deep holes are seldom required, it is more economical, as a rule, in telegraph construction to adopt the latter expedient rather than the former, the sides of deep holes being cut either in steps or obliquely. At some portion of the circumference of the hole the sides should be cut in steps, or if the hole be conical, an inclined plane winding round it may be cut for convenience of the men bringing up the earth excavated. Cuttings made in the undisturbed soil generally have a steeper slope than the sides of embankments made of disturbed earth, technically termed *made earth;* but in such cases grass covering or other dressing is relied on to compensate for the loss of temporary stability due to adhesion. In telegraph construction such steep slopes are frequently inadmissible, the bank standing in water.

237. The stability of friction is alone sufficient to maintain the side of an embankment or cutting at a uniform slope, making an angle with the horizon equal to the angle of repose; the soil if thrown loosely down, assumes this angle. The slope of earthwork is generally described by the ratio of its horizontal breadth to its vertical height—*i.e.*, the reciprocal of the tangent of its inclination to the horizon. The most frequent slopes of earthwork are those termed $1\frac{1}{2}$ to 1, and 2 to 1; wet clay and peat are sometimes 4 to 1, corresponding to an angle of repose of only 14°, while the angle of repose of damp clay and gravel may exceed 45°. A great excess of water, as already stated, tends to destroy frictional stability—*e.g.*, wet sand and mud have no stability of friction,

hence drainage is often very important to the durability of embankments. The absorption and retention of water should be prevented as far as possible; shivers of rock, shingle, gravel, &c., allow water to pass through them without retaining sufficient to prove injurious, but clay and earths containing it absorb water and form a paste with it. Sand and gravel, however, having no adhesion, but depending only on friction for stability, are unsuitable for embankments which have to stand sometimes in water; under such circumstances clay, and mixed clay and loam, do not lose their adhesion completely, and hence stand where sand or gravel would sink; but clay and earth containing clay as an ingredient, have their frictional stability and adhesion diminished by exposure to air and sun. From the above it appears that embankments supporting cable sheds on river banks should not be made of sand, they should have a slope of 3 or 4 to 1, should be somewhat larger than actually necessary to fulfil the purpose required to allow for cutting away by water, and they should be periodically examined and kept in good repair, to enable them to resist, as far as possible, the action of water during flooding of the surrounding ground. Embankments to be kept dry are preferably made slightly steeper than the angle of repose would indicate, adhesion being depended on to impart the required extra stability. The object of this is to expose as little surface as possible to the atmosphere; but such steep slopes should be avoided where the bank may have to stand in still water, and cannot be protected by dry stone, or other similar means.

238. The tools used in earthwork are divided into four classes —viz., 1. Those for loosening and detaching the soil from its natural position; 2. those for handling the detached soil—*i.e.*, lifting, spreading it, &c.; 3. a vehicle for conveying the earth; and 4. a tool for ramming and so consolidating it in its new position. Soft soil may be detached by the same tool as is used to handle it, but in hard ground these operations require different tools. The most useful instrument for loosening soil in digging holes for telegraph posts is a single-bladed pickaxe, the second blade being dispensed with to reduce the size of the instrument, and thus admit of its use in a more confined space. The length of blade should be about 1 foot, and it should not exceed 10 lbs. in weight; the point should be chisel-shaped, about an inch wide, and of steel. A crowbar used as a jumper (described below), and (in India) a khuntie, a kind of jumper used for earth, are used in loosening hard soils in digging holes; the crowbar should be steeled at the end, it is seldom applicable economically, being used then for very hard soil. The khuntie is a broad-bladed jumper, with a wooden handle about 5 feet

long, differing in pattern slightly in different parts of the country; the blade varies in width from 2 to 4 or 5 inches, its depth is about 6 inches; this instrument is a very economical one in the hands of those natives generally using it, for digging small holes 6 to 12 inches in diameter in ordinary ground; but the pick is more economical where applicable—viz., for holes of cross sectional area sufficiently large for a man to work in. The heart-shaped spade shovel is the most useful instrument when the earth is loosened with the shovel, when it has merely to be lifted the straight-edged shovel is more economical. Shovels are used in many parts of India, but the commonest tool for digging is the *phaora*, a large bladed hoe. The phaora differs in shape and size in different parts of the country, and when of suitable shape and size it is more economical in the hands of natives for digging holes and general purposes of telegraph work than the shovel and pickaxe. The phaora blade for ordinary purposes should be about 6 inches wide, and the same shape as the blade of a straight-edged shovel; for hard ground a few of the narrow shape, about 3 inches wide, resembling an adze, are very useful. The handle sockets of picks and phaoras are frequently made too shallow and thin—thus the handles break and get loose frequently in use, and the tool often fails at the eye; the sockets for the handles should be at least $3\frac{1}{2}$ to 4 inches deep, and the iron surrounding the eye should be thick and sound. Phaoras are sometimes made with a neck of iron between the eye and the blade; such tools break at the neck, and should be avoided; the blade of a phaora should spring directly from the socket, and should be thickened towards the eye. Care should be taken that the handle be not too long, or the workman may cut his foot, and a long handled phaora cannot be used in a hole; the point where the handle is held should be the centre of the circle described by the blade, a phaora blade being inclined to its handle at a more acute angle than that between the blade and handle in an adze, the former tool requires a shorter handle than the latter. The phaora appears better adapted to use in a hole than the spade. In Europe, earth is usually conveyed in small quantities in wheelbarrows constructed especially for this purpose; in India baskets are employed; in telegraph construction, as a rule, stout baskets should be used, they are more generally useful and more portable than barrows; the latter can seldom be used in telegraph construction. Rammers are made of cast iron with wooden handles, or entirely of wood hooped with iron, to prevent splitting; the best kind of rammer is a wooden one with the handle and head cut from one piece of wood. Rammers are of different weights—15 lbs. is a common weight in India. As

these tools are heavy it is better to make them, when wood can be got, when and where required, than to carry them long distances; excellent rammers are made from pieces of branches of trees cut at one end to form the handle; these are made as required in a few minutes, and can be burnt when split or no longer required.

239. The positions of post holes are usually marked by stout pegs driven in the ground in the alignment decided on; the holes for the posts should be dug on one side of the peg, that the peg be not removed until the post is planted; holes for angle posts are necessarily dug round a central peg; in this case additional pegs may be placed, indicating the place of the peg removed. In all cases, before commencing the hole, a boundary line should be cut with the spade or phaora marking the extent of the intended excavation. If the hole do not exceed 4 to 5 feet in depth, the earth can be lifted with the spade or phaora by the digger, but for deeper holes, the basket and a second man are necessary. In digging holes in which the depth exceeds that at which the soil will stand with a vertical face, it is necessary to cut the hole with sloping sides, to cut the sides in steps, or to support the surrounding earth by planks placed against the sides, and kept there by struts placed across the hole; the first method is the most economical when such deep holes are seldom required, but for a large number of holes, probably the timber support is cheaper, but it requires more skill to apply. The best method in any particular case must depend on local circumstances; in India it will generally be found that planking is difficult to procure, expensive to carry, and the labour is too unskilled to use it without very strict supervision, hence it should be dispensed with as far as possible. The liability to slip may be reduced by depositing the earth excavated a few feet distant from the edge of the hole. When excavating on the bank of a river, operations may frequently be facilitated by regulating work on the deeper part by the state of the tide; neglect in this respect may render pumping necessary at great additional expense. As some kinds of earth rapidly lose their adhesion when exposed to the weather, deep holes should not be dug until actually required. In bad soil it sometimes happens, if the work of excavating be carried on continuously by relays of men, and the hole be used immediately it is ready, expensive measures of precaution may be dispensed with, and an operation otherwise very difficult and tedious may be performed with comparative ease and expedition. The earth is raised from deep holes—1. By means of baskets hauled or handed up; 2. by platforms erected at every 5 feet of the depth—the earth is handed up by men stationed on these platforms with

spades; or, 3. the men at the bottom of the hole fill baskets, which are carried up as filled by other men; in this case the sides of the hole have to be cut to admit of the men walking up and down, or ladders have to be used. The first and third modes are more generally applicable in India, and inclined planes of natural earth, running round the circumference of a conical hole, are the cheapest and most convenient means of ascent and descent. Earth may be thrown with the spade 4 to 5 feet vertically upwards, or 6 to 10 feet horizontally. Earth having a vertical face may be loosened by cutting away the earth underneath and at the sides, and if the earth does not crack, driving in wooden wedges above until a quantity is broken off and falls; holes may be increased in width in this manner with much less labour than would be required to widen them by digging from the top downwards; soil for an embankment may be loosened in this manner if a steep slope of earth be at hand. For ordinary poles the holes are often dug long and narrow, sometimes with the greatest diameter across the alignment; in India they are commonly dug oval in plan; in France they are dug rather more than a yard long, and rather wider than actually necessary to insert the post: the object of greater length in one direction is to enable the workman to use his tools with the least excess of excavation beyond that actually required to insert the post. If the post to be inserted be unprovided with cross feet, buckled plate, or other fittings rendering a large hole necessary, the hole may be cut with a khuntie or other form of jumper; in France the holes are completed in depth in this manner; in America, holes 15 inches in diameter, are dug 3 feet with the shovel, and then 2 feet with an auger.

240. Holes for telegraph poles are sometimes bored, a practice lately adopted in England; the instruments used consist of the jumper for hard soils and stones, and a kind of worm for ordinary soil. The jumper is a bar of wrought iron, about 4 feet long, steeled at the cutting end, where it may be terminated by a chisel edge or a point. It is used by being raised and let fall on the rock to be cut, being turned slightly round between each blow; lengthening rods or a rope are applied to lengthen the tool as the hole is deepened; this is the most efficient mode of using the jumper, and is termed churning, the jumper so used being termed the churn jumper. Sometimes the tool is hammered instead of being raised and let fall, but this is less efficient, although less destructive to the tool than churn jumping. The worm is generally employed for soft rock, but in a modified form this tool is very economical for general use for boring holes for telegraph poles; this form consists of a hollow rod terminated

by a small boring screw, above this screw is a helical flange, the size of the hole to be bored; this flange is not truly helical, however, thus it breaks the soil as it is screwed in. The tool is turned by two men by means of a cross bar of wood, and being drawn up at intervals, it brings with it the earth loosened; below the flange is a valve opening into the hollow stem of the tool for admitting the air into the bottom of the hole, thus counterbalancing the pressure of the atmosphere and allowing the earth and tool to be withdrawn with greater ease. This tool does not work well in loose soil, as sand, but in ordinary firm soil two men can bore with it a hole 10 inches in diameter and $4\frac{1}{2}$ feet deep in twenty minutes. For very soft loose soils a tool termed an auger is the most economical; this is simply a hollow cylinder with a slit up one side and an oblique cutting edge at the bottom, it is turned round by two men as the worm. The worm and auger lift the soil, but the jumper does not, and a peculiar kind of scoop called a Spanish spoon, or earth ladles, are used to raise the broken soil. The worm described above has been patented in England. The use of boring tools for planting posts is cheaper than spade digging, while the bored hole has the following advantages:—First, It is more accurately placed, for being very little larger in diameter than the post, the alignment pegged out cannot be unintentionally departed from; second, the soil not being disturbed close to the post, the post is much firmer immediately on erection; third, a greater part of the labour of ramming and consolidating the earth necessary when a large hole is dug is saved. In Bengal a native using a khuntie can jump a hole 3 feet deep and 8 inches square, in ordinary soil, in twenty minutes, using his hands to raise most of the soil. A Hamilton's 16-feet pole may be broken transversely, if placed in a bored hole in ordinarily firm soil, by a horizontal force applied at the summit, without disturbing the surrounding earth; the same pole with cross feet placed in a hole 3 feet square may be pulled over immediately after erection, the hold on the ground being much less than in the former case, and less than the ultimate load of the post (5 cwt. at 16 feet from ground line). Most of the wooden poles erected in India were placed in small holes jumped with the khuntie, and the posts stood satisfactorily; the British Government Postal Telegraph Department use boring tools for planting poles, with satisfactory results as regards both efficiency and economy. For boring holes in rock the jumper is the tool generally employed; rock when very hard is split by steel wedges driven into holes cut with the chisel.

241. In filling in a large hole round a pole the earth should

be carefully rammed; this may be done by filling the earth in layers, each about 9 inches deep, and then ramming over the whole surface, or a man may walk round the hole ramming, while another supplies the earth gradually; the addition of stones, or a little water, assists the process of consolidation. The earth should be heaped round the pole, as it will sink when soaked by rain, and if not heaped up a hollow will be left. The surface mould and grass, if any, should be reserved when commencing to dig, for replacing on the top after filling in, as it may prevent the heap round the pole being washed away instead of sinking. Poles planted on an incline, as the side of a hill or embankment of a road, have a tendency to deviate from the vertical line in the direction of the normal to the surface of the ground; this is very difficult to prevent, and should be guarded against in filling the hole—the earth should be more carefully consolidated on the lowest side, and a small portion only of the surplus earth should be thrown on the slope above the post. In making an embankment the first process is removal of the surface mould and grass, if any, reserving this for dressing the slopes. For the body of the embankment the earth should be thrown down in horizontal, or preferably slightly concave, layers, about 9 inches thick, each layer carefully rammed separately. Water may be sprinkled over each layer if the earth be dry, to assist the process, and care should be taken that the bank be built up entirely of horizontal or concave layers, as earth thrown on the sides is more likely to slip than when spread horizontally. After the required height has been attained, the slopes and top should be trimmed to smooth and regular surfaces, dressed with 6 inches or more of surface soil or clay, and covered with sods or sown with grass seed. When the ground on which an embankment has to be made is inclined, its surface should be cut into steps, as shewn in fig. 58, AQ, to prevent the earth of the embankment from slipping down. If the embankment be exposed to still water, its sides may be roughly pitched with dry stone, about a foot thick; but the pitching with stone is not generally necessary, and would, in most cases, be too expensive. Stiff clay or river silt may be used, and the slope should be 3 or 4 to 1. An ordinary embankment of earth, covered with grass, is found to resist the action of water sufficiently well to serve for supporting cable sheds on the low

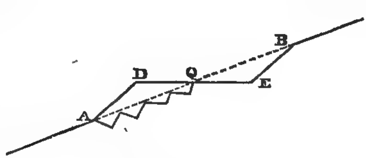


Fig. 58.

banks of rivers; if repaired regularly, such embankments stand well during the rainy season in India, often standing in several feet of water for long periods; but after each rainy season they should be thoroughly repaired, and rat holes and other openings closed. The ground immediately surrounding an embankment should be drained, so that water may run off as quickly as possible.

242. An embankment will sink after formation one-twelfth to one-fifth of its height, according to its dimensions, nature of the soil, and the mode of formation; the two latter conditions being the same, the sinking has been found to vary nearly as the cube of the height. Earth formed into an embankment, if well rammed, occupies less space than before excavated by about one-tenth of the earth excavated; gravelly earth was found to be compressed about one-twelfth. The size of the heap of earth round a newly erected telegraph pole may thus furnish an indication of the care taken to ram the earth.

243. When an embankment is required to be watertight, it may be made so by means of clay puddle, made of clay containing a little sand freed from large stones, roots, &c., worked into a paste with water, the puddle may be covered over the bank for a depth of 6 inches to 1 foot; but as it is liable to crack when exposed to the sun, the best mode of applying it is by filling with soft puddle a trench cut in the bank. The puddle is then protected from the action of the air and sun; such a trench is termed a puddle gutter. The silt of tidal rivers may be used as puddle.

244. The earthwork in telegraph construction is very simple in form; the cubic contents may be obtained nearly enough to the truth by the application of elementary formulæ, which it is not considered necessary to reproduce.

245. The quantity of work which can be done by one man varies with the nature of the soil to be excavated: in loose sand or mould not requiring the pickaxe, one man in England will excavate 20 cubic yards per day; in compact earth or clay, the pickaxe being used, 8 to 10 cubic yards—the earth being loaded into barrows, wheeled by wheelers. In India it is said to be difficult in some districts to get a coolie to dig more than 50 cubic feet per day with European supervision, native contractors getting more work out of the men. In digging holes for poles 3 feet square and 3 feet deep, in ordinary soil, three holes or 3 cubic yards is the lowest task which should be considered a day's work—4 cubic yards may frequently be obtained. There being a difficulty in getting 3 yards done per man, the men pleading inability to do more, a trustworthy man was told by the author

to dig as many such holes as he could during the day, as an experiment. This man, although a small, thin man, dug 8 cubic yards, and said he could have done 10, but was afraid of the other coolies. Four or 5 cubic yards cannot be considered an excessive requirement. Digging in small holes is more laborious than in more extensive excavations affording plenty of room to use the tools; the additional labour of raising the soil from the hole is generally considerable. In the above estimate of work done by Englishmen the earth is assumed to be merely placed in barrows, and not raised as in digging a small hole. In managing a gang of coolies digging ordinary pole holes the most economical mode is to allow no more than one man at each hole, unless absolutely necessary, an exceptional case; to allow only the phaora unless the khuntie or pickaxe be absolutely necessary, and to state the amount of work considered a day's task, on completion of which, however early, the man should be allowed to leave work for the day. By these means waste of time is prevented, and work may be obtained with less supervision. Upon one occasion, when great difficulty was experienced in getting a fair day's work done, by allowing the men to leave work on completing a task the difficulty was removed, and the task found impossible before was completed by mid-day. During unhealthy seasons, and when work is carried on in hot weather, the task should be reduced, particularly if sickness appears amongst the men. The labour of spreading earth in layers and ramming it is from one and a sixth to one and a third that of shovelling the same quantity of earth into a barrow.

246. The following are given, on the authority of Rankine, as examples of the day's work per man performed in jumping holes:—

	Cylindrical inches of hole.
In granite by hammering, ...	100 to 150
In granite by churning, ...	200 nearly
In limestone, ...	500 to 700

In granite jumpers require to be sharpened about once for each foot bored, and steeled once for every 16 or 20 feet; the length of iron wasted in using them is about one-tenth of the depth bored.

247. The principal laws of the stability of loose earth are stated in Part I., chapter iii., sections 2 and 3. The adhesion of earth is not usually considered, but when undisturbed this adhesion is an important element in holding poles fixed in the ground, as will be evident on consideration of the resistance offered by the ground to the movement of a pole which has

either stood long enough for the disturbed earth to become consolidated, or has been placed in a small hole. Lateral support is no doubt an important element, increasing the resistance of earth; but the importance of adhesion in holding poles firmly is proved by the fact, that an ordinary pole placed in loose earth may be readily dragged over by a transverse load, whereas the same pole inserted to the same depth in the same kind of soil *undisturbed*, may be broken by a transverse load, without cracking the surrounding ground. Hence the importance of disturbing the surrounding ground over as small an area as practicable when digging pole holes, foundation pits, &c.

Section III.—*Foundations.*

248. A foundation is defined (Paragraph 145) as that portion of the earth on which a structure immediately rests; in its extended signification it includes any works executed to prepare the ground for bearing safely the structure to be placed upon it, as when planking is placed over soft ground to distribute the load. The pressure of a structure on the earth is resisted by the friction and adhesion of the earth, but in general the friction alone is relied on in earth commonly so called. A foundation on land consists usually of an excavation or foundation pit, and where necessary, of a structure at the bottom of the pit to form a secure base for the principal structure to be erected; in some cases the natural surface of the ground forms the foundation, requiring no preparation, as in forming an embankment on firm level ground. When the earth has sufficient stability to support a projected structure without an artificial base, the foundation is termed *natural;* when the earth has not sufficient firmness, an artificial base is necessary to enable the earth to support the weight, and the foundation is termed *artificial.*

249. Most earth is more or less compressed by the weight of a structure; the object of preparing a foundation is to restrict their sinking within the narrowest limits, and to ensure that such slight sinking as is unavoidable shall take place equally over the whole area of the foundation. Most telegraph structures are composed of parts so connected that unequal sinking has not to be feared; but in structures built in courses as brickwork and masonry, of considerable weight and extent, but unsuited to resist tension, unequal sinking, even when slight, is exceedingly destructive, rending the structure through the whole extent of its vertical height. The small area covered by the base of even the largest masts does not exceed 16 square feet, and is often much less, hence there is no difficulty in selecting so small

a site composed of the same kind of earth; but in forming an embankment or building a wall, care must be taken to prevent unequal sinking of the foundation.

250. The conditions of stability of the joint between a structure and the surface of its foundation are the same as those of any other plane joint; the surface of the foundation should be as nearly as possible perpendicular to the pressure of the intended structure, and the centre of pressure should not deviate from the centre of gravity of the base of the structure beyond a certain fraction of the diameter of that base, measured in the direction of the deviation (Paragraph 163). It is evidently necessary that the earth immediately beneath a structure be not disturbed by the action of water, by the alternate contraction and expansion and disintegration consequent on exposure to the changes of weather; hence, even when the earth is firm enough to bear a structure on its surface, excepting in the cases of embankments and foundations on rock, structures have their bases below the natural surface of the ground. In Britain the depth should be at least 3 feet for sand and 4 for clay; in most parts of India frosts do not occur, and the changes of temperature being less extreme, the depth at which foundations should be placed to ensure protection from atmospheric changes is not usually so great; but in some soils the alternations of great heat and excessive dryness with the heavy rains of the wet seasons, may more than counterbalance the advantage of more uniform temperature.

251. Foundations on rock merely require that the rock be reduced to a level surface, or a series of steps perpendicular to the direction of the pressure of the intended structure; soft and loose pieces of rock should be cut away, and the hollows filled with bèton or concrete or rubble masonry; for a mast it is merely necessary to jump or cut a hole for the foot of the mast to prevent lateral motion. The extreme intensity of pressure admissible on a rock foundation is one-eighth of that which would crush the rock. Professor Rankine states the ordinary average pressure of foundations on rock at least as strong as the strongest red brick, to be about 9 tons per square foot; while on sandstone so soft that it crumbles in the hand, $1\frac{3}{4}$ ton is borne with safety.

252. Foundations in earth depending for its stability on friction alone, depend for their security upon the fulfilment of the condition that the weight of earth displaced by the foundation shall not bear less than a certain ratio to the weight of the structure to be supported; this ratio depends on the angle of repose of the earth, and the mass displaced is as the product of

the depth and area of the foundation pit; in other words, the less the frictional stability of the earth the greater must be the cubic capacity of the foundation pit. In firm earth the greatest pressure per square foot varies from one to upwards of one and a half ton, and within these limits it is not necessary to dig the foundation pit below the distance necessary to render the foundation secure against the injurious effects of changes of weather. In soft earth, which will not, unless certain precautions be taken, support the structure with safety, it would be too costly to excavate very deeply in order that the weight of earth displaced by the foundation should bear the necessary ratio to the weight of the structure to be supported; in this case the pressure is distributed over an increased area by an artificial foundation. Let x represent the depth of the foundation, w the weight of a cubic foot of the earth, and ϕ its angle of repose; if the pressure of the structure be uniformly distributed over its foundation and the intensity of the pressure be p, the weight of earth displaced by the foundation should not bear a less ratio to the weight of the structure than that given below—

$$\frac{wx}{p} \text{ should not be less than } \left(\frac{1-\sin\phi}{1+\sin\phi}\right) \quad \text{........(1.)}$$

If the pressure be not uniform, but uniformly varying, then the quantity p in the above formula should be replaced by the greatest intensity of pressure, and in addition the least intensity must not be less than wx. Some examples of the value of the function of the angle of repose are as follows:—

ϕ	15°	20°	25°	30°	35°	40°	45°
$\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2 =$	0·346	0·224	0·165	0·111	0·073	0·047	0·0295

In applying the above formula the quantities p and w are fixed, and x has to be adjusted; but if x be large, it becomes necessary either to dig deeply and fill the hole to a certain height with some stable material on which to erect the required structure, or the foundation pit may be made much wider than actually required, and filled with stable material to reduce the intensity of pressure (p) by spreading the load over greater surface of foundation.

253. Where the ground is soft, but not so soft as to be semi-fluid, as mud, silt, or peat, it may be treated in one of two ways: —First, The ground may be consolidated by driving piles until it is so compressed that the piles are prevented from sinking by friction. The piles may be of wood, iron screw piles, or of sand; the last are made by boring holes in the ground with a large

auger and filling them with sharp sand. Piles must be used with great caution, as they break up the ground; piles and the pile-driving machine are usually excluded on account of expense. When piles are thus used to consolidate the earth, it may be considered in applying the formula given, that a trench has been dug to the depth the piles are driven, and filled with stable material. Second, the intensity of the pressure may be reduced by distributing the weight of the structure over an area increased by artificial foundation: in this case the trench may be filled with sand, gravel, broken stone, bèton, or concrete; if a solid mass be used, as concrete, the pressure may be considered as distributed over the whole surface of the layer, provided this layer do not extend beyond the base of the superposed structure by a distance greater than its thickness; if loose materials be used the intensity of pressure should be calculated on the area of the base of the building only. If $\left(\frac{1-\sin\phi}{1+\sin\phi}\right)^2$ be represented by k, and w^1 be the weight in lbs. of a cubic foot of the material with which the trench is to be filled, being about 90 lbs. for sand, then the required depth x of the foundation pit is given by applying formula (1)—

$$x = \frac{pk}{w^1 - wk}; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.)$$

If the structure to be erected on the artificial foundation be an embankment, then the sides of the foundation pit should be inclined at the angle of repose of the soft material of the ground, and only the slopes of the embankment should be placed vertically above the slopes of the foundation, the upper edge of the embankment slope being vertically above the lower edge of the slope of the excavation. In applying sand or gravel, it should be well rammed in layers of not more than 1 foot thick; if concrete be used it should be also well rammed and allowed to set before being loaded. If the pit be near a river so that the foundation is for a long period below water, common concrete is wasteful, as the lime is soon removed and the mass is reduced to the condition of gravel—it is obvious gravel is equally useful and cheaper; in such cases gravel should be employed, or if concrete be used it should be hydraulic—*i.e.*, bèton. It will frequently be found cheaper to apply one of the expedients described below rather than concrete or bèton.

254. When the earth is very soft, almost semi-fluid, as mud, silt, peat, &c., the best kind of artificial foundation is a platform of planks, formed either of a grating of timber planked over, or of planks in two layers, those in one layer being at right angles

to those in the other; or a platform of fascines or fagots placed in layers, those in each layer being placed at right angles to those in the layers immediately above and below; these are staked and lashed together to form a kind of platform, a layer of sand, gravel, or other stable material is spread over the platform to distribute the pressure, and on this the principal structure is commenced. These foundations may be expected to sink a little, and the load should be distributed over them as equally as possible. Timber under wet earth is very durable, and may be safely used; but near the surface and in dry earth it decays, and is attacked by insects.

255. When a firm stratum underlies a very soft one, piles or other supports may be put down to rest on the firm stratum and form a foundation; but this work is very expensive, and the expedients already given will generally be found sufficient. Sand and gravel are excellent for foundations so long as they are not exposed to the action of water, and are not allowed to escape; but if they be exposed to the action of water and be not confined, they lose their frictional stability and ooze away from under the structure; hence, in placing a structure on sand or gravel, or using such materials for artificial foundations, this property must be considered. An excavation near a structure on a foundation of wet sand may cause sinking, in consequence of the oozing out of the sand; it is usual when such is to be feared, to surround the foundation with sheet piling, to sink iron cylinders, to use caissons, &c. If a stratum of firm ground have beneath it a soft soil, formulæ 1 and 2 should be applied to find if the thickness of firm soil is sufficient to bear the weight of the structure.

256. In making a foundation under water the methods employed have the same end in view, and are in principle the same as in land works; the mode of execution is necessarily modified by the altered circumstances of the case. If the water be running and the ground likely to scour, the work is most difficult and necessarily expensive; probably screw piles are best adapted to the cases likely to arise in practice, a number of piles being screwed into the ground to the firm stratum, or beyond the possibility of being loosened by scour, a platform is erected over their heads. The platform may be of timber or of iron bolted to the pile heads. The piles when they stand much above ground, should be braced together by means of cross and diagonal irons fastened with bolts, the whole forming a firm foundation on which to erect the required structure. The great advantage of screw piles over timber, in the case supposed above, is the ease with which they may be driven, requiring no pile-driving

machine; they should be of small diameter in the rod, and driven by means of strong iron levers gripping the pile on the principle of the gas tongs. It is very seldom necessary to erect a mast or pillar in running water as supposed above, but it commonly occurs that masts have to be erected in places which for long periods are under water; the work can generally be carried on when the water is either very low or entirely absent. In making a foundation in still water on soft soil not likely to scour, if the water periodically subsides the foundation may be the same as for the similar case on land; if the water cannot be excluded, and it becomes necessary to construct a foundation on the soft bottom, a platform of fascines or timber may be loaded with stones or other suitable material sunk on the spot, and an embankment of stones or other available material formed on this platform to receive the superstructure. In telegraph structures the commonest case occurring in practice is that of a high mast to be erected on a river bank; the soil is frequently bad; often to reduce the span the masts are erected on ground liable to inundation, and the foundations are generally necessarily carried below the firm surface soil, in order to get a firm hold on the ground; but unequal sinking has not to be feared, and the pressure may easily be distributed by any of the modes described, generally at very small additional expense. Considerable sinking of a mast on the rising of the adjacent river, by loosening the stays may endanger the structure. Some rivers have to be crossed by masts placed in the stream, stays are then inadmissible, as they catch driftwood and may cause the mast to be carried away; it is essential in this case that the mast be firmly fixed, as additional stiffness should be gained by fixing the end, and consequently the foundation be constructed with great care, to avoid unnecessary expense. River cable huts have often to be erected on ground liable to be rendered unsafe by inundation; by the means indicated such ground may be made to bear the embankment safely, and an embankment may with due precaution be formed in a situation where at first sight it might appear impossible for it to last. By the use of fascines and stable material a path may be made through the mud of a river bank to a cable house which at low water could only be approached with great difficulty by wading through the mud. Foundations are greatly improved by being drained, but this resource is seldom at command. The use of the excellent appliances commonly employed in great engineering works is excluded by reason of the smallness of the individual works, the infrequence of the occurrence of the difficulties, and the disproportionate cost of the appliances and their carriage to the cost of the work to be constructed.

SECTION IV.—*Cementing Materials.*

257. Calcareous cements, as their name implies, have for their essential ingredient lime. Gypsum, or plaster of Paris, is pure sulphate of lime; the other calcareous cements are composed of hydrate of lime combined mechanically with certain matters to increase the bulk, with a view to economy and diminution of the variation of bulk which takes place when the cement hardens or sets, and frequently combined also with matters which by their chemical properties modify materially the properties of the mass. The hardening of gypsum is due to the combination of the sulphate of lime with water; other calcareous cements solidify by reason of the lime combining with carbonic acid to form the carbonate of lime, by combination of the lime with silica, and again into compound silicates with other bases, principally alumina, or these two causes may operate together to produce the effect.

258. *Pure, rich,* or *fat* lime is obtained by calcining, at a bright red or higher heat, limestones consisting of almost pure carbonate of lime, as chalk or marble; the process takes thirty to fifty hours, at the end of which time the carbonic acid and water if any, in combination with the lime have been driven off, and pure quicklime or caustic lime remains. The chemical equivalents, of lime being 57 and of carbonic acid 44, pure carbonate yields about 56 per cent. of lime. The stones are burnt either in permanent or temporary kilns, varying greatly in shape and size, seldom exceeding 12 feet in height; the fuel employed in England is usually coal, the quantity used being about one-fifth to one-sixth of the lime produced. In India the fuel most economically obtained on the spot is employed—wood, charcoal, or dried cow-dung being used, according to circumstances; the latter, however, is least suitable to the purpose; fuel being easier transported than stones, it is usual to burn the stones near to where found, and in temporary kilns. Whatever the original colour of the stones, the lime is quite white or light brown in colour; it has no tendency to recombine with carbonic acid so long as it is kept dry. When mixed with water rich lime swells to from two and a half to three and a half times its original bulk, becomes very hot, and falls to a fine powder; this powder is the hydrate of lime, being a combination of lime with one equivalent of water; the composition of the hydrate is therefore 76 per cent lime and 24 per cent. water. The hydrate is sparingly soluble in water, therefore by the application of abundance of water the lime may be completely dissolved. In the state of hydrate the lime has a great affinity for carbonic acid; slow combination with the carbonic acid present

in the atmosphere and crystallisation of the resultant carbonate of lime produce after the lapse of years a very hard material. The absorption of carbonic acid is most energetic at first, and progresses slower in each successive interval of time; thus the lime does not appear to ever recover the full equivalent of the gas it was combined with when a component of the natural limestone. One year after mixture lime acquires a tenacity of 40 lbs. per square inch (Vicat). It is essential to the hardening of rich lime—1. that the water combined with it mechanically and chemically should be allowed to escape, and, 2. that carbonic acid be present; if, therefore, a paste be made with rich lime this paste will not harden under water. If, however, the water mixed with the lime be rapidly evaporated or otherwise removed, the carbonate of lime as formed will not be in a solid mass, but will fall to powder. Slow evaporation of the water is favourable to the ultimate hardness of the carbonate.

259. A mixture of slaked lime and sand made into a paste with water is termed *mortar;* the consolidation of the mixture depends entirely on the properties in this respect of the lime as described above, the sand forming with the hydrate and ultimately with the carbonate a mechanical mixture only. The sand is used to increase the bulk of the mortar, and thus economise lime; to increase the resistance of the mortar to crushing—it diminishes, however, the tensile strength, and if too much be added the mortar will fall to powder as it sets; and to diminish the amount of shrinking as the mortar solidifies. The quantity of sand may be as much as three times that of the lime, but above two and a half times there is a decided deterioration in strength; 2·4 parts of sand to one of pure slaked lime in paste is, according to Vicat, the best proportion. The sand should be very clean, being washed if necessary to remove loam or clay; it should not be very fine nor exceedingly coarse, and rough angular grained sand is better than smooth; pit sand is preferable to river sand; sea sand should be washed to remove salt before being used. The lime should be slaked twelve to twenty-four hours before being made into mortar, and covered up till wanted; care should be taken not to add too much water, as the process is thereby hindered, and the lime is said to be *drowned.* Care should be taken that the process of slaking has taken place throughout the whole mass, as if unslaked lime exist in mortar the expansion consequent on its slaking in the joints of a building may rend the work. The quantity of water necessary will in general be between one-third and one-half the bulk of the lime. The tenacity of common mortar varies between 21 lbs. per square inch for bad, and 51 lbs. for good quality, one year after mixture (Vicat). Its resistance to crush-

ing 18 months after mixture varies between 440 lbs. and 800 lbs. per square inch, according to the quality of sand used, and whether it be beaten or not—the proportionate increase of strength 16 years after mixture is one-eighth (Rondelet). The above figures are adopted by Rankine, and are confirmed by other observers; thus, Colonel Trotten found the tenacity of fat lime mortar six months old to vary between 23·4 lbs. per square inch with equal parts sand and lime, and 20·1 lbs. with $2\frac{1}{2}$ parts sand to 1 of lime; when four and a half years old these numbers were raised to 40·4 and 29·8 respectively—the lime was measured in paste. The above figures appear to give the limits of variation, but mortar in the interior of thick masonry must be a long time acquiring any considerable degree of strength, and probably seldom if ever attains the strength acquired in a few years by that more exposed. In India it is a common practice to mix a little coarse sugar (*jaghery* or *goor*) with the water used to make common mortar, this hastens the setting of the mortar. Captain Smith found that mortar 13 years old made of 1 part common shell lime to $1\frac{1}{2}$ sand mixed with water containing 1 lb. of jaghery per gallon, had a tensile strength of $6\frac{1}{2}$ lbs. per square inch, while the tenacity of similar mortar prepared without the jaghery was only $4\frac{1}{2}$ lbs per square inch. M. A. Morin's tables in the *Aide Memoire*, compiled after reference to the works of Vicat, Rondelet, Gauthey, and G. Resine are incorrect; it appears the word *millimètre* has been used erroneously for centimetre: this mistake is not made in the *Resistance des Materiaux* by the same author, but the errors have been copied; thus, in the Roorkee College manual, on *The Strength of Materials*, mortar is erroneously stated, on the authority of M. Morin, to have a tenacity of 5,975 lbs. per square inch, brick a tenacity of 27,740 lbs., &c.—these numbers should be divided by 100.

260. If instead of a pure limestone, a limestone containing from 10 to 30 per cent. of silicates of alumina, or of alumina and iron, be calcined, the result is not rich lime, but a mixture of pure lime and the silicates, termed *hydraulic lime;* with a larger proportion of silicates, from 10 to 60 per cent., the product is called *natural cement*, the two materials not being distinguished from each other by a defined line. Hydraulic lime may be feebly hydraulic and differ but little from rich lime, or strongly so, according to the proportion of silicates. The properties of hydraulic lime are as follows:—It slakes less rapidly than pure lime; it solidifies by reason of the lime combining with the silicates to form silicates of lime, alumina, iron, and any other bases present, and by the lime in excess acting as a rich lime and forming a carbonate. Strongly hydraulic lime slakes very

imperfectly, and it is hence necessary to grind it to a fine powder before slaking; not depending for its property of hardening on the presence of carbonic acid, it hardens (although slowly) under water, and it should not therefore be slaked in large quantities. As it slakes with difficulty, it should be left for twenty-four to forty-eight hours after slaking, to make sure the maximum expansion has taken place before employment in mortar. Less water is required to slake hydraulic than rich lime, the action not being so energetic in the latter case the evolution of heat and consequent evaporation are less. The lime expands or contracts in setting according as the silica or alumina is excessive, hence excess of either is to be avoided. Instead of burning limestones containing clay, hydraulic lime may be made artificially by mixing slaked rich lime and clay or chalk and clay together, forming a paste with water, and dividing the mass into small pieces, generally balls, two or three inches in diameter, and after drying these pieces in the sun calcining them. In making mortar with hydraulic lime, termed hydraulic mortar, the proportion of sand used must be less than in the case of common mortar, and less as the lime is more hydraulic; strongly hydraulic lime of good quality will not bear more than two parts by measure of sand to one of slaked lime in paste—in general less should be used. The mortar should be mixed only as required for use. Hydraulic mortar is stronger, and attains its greatest solidity more quickly than common mortar; clean sand should be used, but sea sand and sea water are admissible. Rapid dessication is more injurious to the strength of hydraulic than to that of common mortar; the admixture of organic matter and clay with *any* mortar is very prejudicial, hence the sand to be used should be carefully washed. Hydraulic mortar eighteen months old offers a much higher resistance to crushing than is offered by common mortar sixteen years old; this strength is said to increase one-fourth. Good hydraulic lime has about four times, and ordinary quality about three times, the tenacity of rich lime one year after mixture; its tenacity varies between 100 and 170 lbs. per square inch. The tenacity of good hydraulic mortar is 140 lbs., and of ordinary quality 85 lbs., per square inch one year after mixture (Vicat).

261. Common mortar may be made hydraulic by mixing with it *pozzolanas:* these are mixtures of burnt clay and silica containing little or no lime, and are natural productions of volcanic districts; iron scale and mine dust serve the purpose, and burnt clay ground to powder (termed sūrki) is an instance of an artificial pozzolana in common use in India. The proportions

are usually one part of pozzolana to two parts of hydraulic lime, but these must depend on the proportion of silicates in the hydraulic lime used, the pozzolana being used to compensate for the deficiency of hydraulic properties in the lime. When a mixture of sand and pozzolana are to be used with pure lime to make hydraulic mortar, two to three measures of the mixture may be used to one measure of unslaked lime. Mortar made hydraulic by the addition of artificial pozzolanas is unsuitable for work exposed to the action of sea water; for although it sets well at first in such situations, it has been found disintegrated after a few years' exposure. Artificial pozzolana does not deteriorate by exposure to air and humidity, hence old bricks may be used.

262. Cements are distinguished from hydraulic limes by containing silicates in that proportion required to combine exactly with the *whole* of the quicklime present; thus, when cement has set it contains no carbonate of lime, but is composed entirely of compound salt of silica with lime and alumina, sometimes with iron and other bases when such are present. The composition of the best cement is—

2 equivalents of lime, . .	$57 \times 2 =$	114·0
1 equivalent of alumina, .		102·8
2 equivalents of silica, . .	$93 \times 2 =$	186·0
		402·8

On the addition of water this compound forms a compact stone, composed of the double silicate of lime and alumina. A cement made by calcining stones containing lime and silicates in the necessary proportions, is termed *natural;* if made by calcining an artificial mixture of either ground chalk or pure lime with clay, it is termed *artificial;* the latter is usually burnt in balls two or three inches in diameter, and is at least equal to natural cement. The proportion of clay to lime or chalk varies —four parts clay to six parts chalk is a common proportion, but the best proportion depends on the composition of the clay. When quicklime is used, it should be slaked before mixture with the clay. About three hours is the average time required for calcination, the completeness of which is tested by hydrochloric acid causing no effervescence. Comparing brick and hydraulic and common mortars, the relative tenacity of each, bad common mortar being one, is as follows:—

	Relative Tenacity.
Common mortar, ...	1·0 to 2·5
Hydraulic mortar, ...	4·25 „ 7·0
Brick, ...	14·0 „ 15·0

Hydraulic mortar is used for important works; structures built with common or feebly hydraulic mortar may have the mortar protected by filling the outside surfaces of the joints with cement (pointing), but this must hinder the hardening of the interior mortar.

263. The principal conditions to be observed in applying the above described cementing materials are the following:—The mortar or cement should be used in a rather stiff paste; the stones or bricks to be cemented should be clean; those which are very porous should be soaked in water, and all others well wetted to prevent rapid absorption of moisture from the cementing material; the joints should be as thin as possible, and every block should be well pressed home, in order that no vacuities be left in the joint. Mortar is sometimes used fluid, it is then poured into the work (grouting), but it is inferior in strength to mortar made with less water. Mortar adheres most strongly to bricks and least to wood; of stones of the same kind it adheres most to the roughest and most porous, amongst different stones it adheres most to limestones and least to sandstones. For the first few years the adhesion of mortar to stone and brick is greater than its own cohesion. Hydraulic cements adhere to polished as well as to rough surfaces, hence they may be used to cement porcelain and iron as in cementing stalks and cups in insulators, for which they are admirably suited, and to which purpose they are frequently applied (Paragraph 290). *Portland cement* is an artificial cement manufactured from chalk or limestone and clay. *Roman* or *Parker's* cement is a natural cement made from stone. Cements do not slake, they set in water or air in a few minutes, and become very hard in a month; the admixture of sand with cement diminishes its tenacity, and should be avoided where great strength is required. Shrinking and cracking are reduced by the admixture of sand when the cement has to dry fully exposed to the air, and sand is sometimes mixed with cement to increase the bulk of the material and thus reduce its cost. The proportions vary between one and two parts of cement to one of sand. Experiments made at Chatham in 1857, proved that Portland cement deteriorated much more by admixture of sand than Roman cement:—when 11 and 30 days old a mixture of one part cement to two parts sand was somewhat less than half as tenacious as pure cement; the experiments were made by tearing joints asunder. Professor Rankine states that a mixture of equal parts sand and cement is only one-fourth as tenacious as pure cement; this estimate appears too low. Mr. Grant made an exhaustive series of experiments on Portland cement of the best quality. The tenacity of cement weighing 112 lbs. per bushel was—one week after mixture, 200, one month,

300, and one year, 480 lbs. per square inch; of equal parts cement and sand the tenacity was 43 lbs., 137 lbs., and 310 lbs. respectively; and of one part cement to two parts sand, 23 lbs., 55 lbs., and 205 lbs. respectively. A cement weighing 123 lbs. per bushel was more tenacious, and the diminution of tenacity on admixture of sand, was proportionately less. The results of Mr. Grant's experiments with Roman cement were unsatisfactory. The tenacity of ordinary cement is equal to that of good stock bricks, and from the above figures it will be seen the best cements are much stronger. Sir C. W. Pasley found the tenacity of cement made of chalk lime and blue clay a few days after mixture was 125 lbs. per square inch. Professor Rankine, *Civil Engineering*, states—The tenacity of Portland cement made from compact limestone and clay, thirty to fifty days after mixture, varies between 1,200 and 1,550 lbs. per square inch; these figures do not agree with those obtained by Mr. Grant for the highest quality cement, and the authority on which they are given is not stated. Mr. Grant found the resistance of Portland cement to crushing was as follows:—

Three months old 3,800 lbs. per square inch.
Nine „ „ 5,988 „ „ „ „

A mixture of one part sand and one part cement three months old offered a resistance equal to 2,488 lbs. per square inch, and when nine months old the resistance was 4,542 lbs. per square inch.

264. PLASTER OF PARIS or GYPSUM is a sulphate of lime from which the water has been expelled by calcination, it is in the form of a white powder. If mixed rapidly with water, it combines with a portion of the water to form a hydrate, the mass swells, heat is developed, and the superfluous water evaporates; the mixture quickly solidifies and forms a compact granular solid. More or less water is added according to the purpose to which the plaster is to be applied; the average quantity is about equal in bulk to the powder employed. The use of hot water hastens the setting of plaster, and an admixture of salt or glue hinders the process; but these expedients impair the strength of the product. Plaster has a tenacity of about 70 lbs. per square inch when set (Rondelet). It is used for cementing poles into holes jumped or cut in rock, and into masonry, being preferred to cement for these purposes when the poles have been injected with sulphate of copper, as the lime in cements and mortars decomposes the sulphate. Its property of expanding in setting renders it useful for fixing iron in stone, &c.

265. Plaster is also used to fix the stalks and cups of insulators, but used alone its property of expanding when setting may cause an internal stress very prejudicial to the strength of the insulator;

the best mixture for this purpose appears to be a mixture of plaster, Portland cement, and sand, the contraction of the cement and expansion of the plaster neutralise each other; the sand besides reducing the cost, by increasing the bulk tends also to reduce the alteration of bulk to a minimum in the event of the other ingredients not being in the proper proportions. To reduce the expense, the stalks are sometimes cemented with a mixture of smith's ashes and resin, the expensive cement being used for cups and hoods only. Muirhead's cement is composed of 3 parts Portland cement, 3 parts rough sand, 4 parts smith's ashes, and 4 parts resin, by weight (Clarke and Sabine); but it is better to make two cements of these materials than to mix them in one. A cement composed of plaster, with glue white-lead and sulphur, has been employed for insulators.

266. A mixture of smith's ashes and resin is a good cement for many purposes; or equal parts of smiths' ashes and rough sand may be used instead of the former alone—the weight of resin employed should be about equal to that of the mixture.

267. Sulphur may be used as a cement, or a mixture of sulphur with about 10 per cent. of iron filings; these cements are strong, particularly the latter, but great caution is necessary in applying them. Sulphur acts on metals and India-rubber—the expansion of sulphur cements, due to combination of the sulphur with any metal in contact with it, limits their employment; when used for insulators the expansion splits the cups and hoods after a short exposure to the weather.

268. Marine glue is a cement much used for cementing plates into battery boxes, &c.; it may be made of 12 parts benzole, 1 India-rubber, and 20 powdered shellac; these should be mixed with cautious application of heat; it is applied with a brush.

269. Common glue is a cementing material of very limited use, as it will not resist exposure to the weather used alone, but it will if mixed with white lead and linseed oil, the whole being boiled together and applied as common glue (Nicholson, *Ency. Brit.*) Glue is made from the scraps of hides previous to tanning; the best quality is nearly transparent. Glue should be prepared as follows:—It should be broken into small pieces and soaked for twelve hours in as much water as will cover it; it should then be melted at a temperature not higher than 212°, simmering gently for from one to two hours, and water added until it runs from the brush in a fine stream; the soaking is sometimes dispensed with. Glue is used to join wood, paper, &c., principally wood; the joint is frequently stronger than the wood joined, and if torn asunder almost invariably tears out some of the fibres of the wood; it holds to mahogany and deal

better than to most other woods, and holds better sideways than endways of the grain; in the latter case more glue is required, and it should be allowed to soak in. Glued joints should be thin, thin joints being stronger than thick ones; the surfaces should be well wetted with glue, then pressed together in various ways to press out as much glue as possible, and then if possible kept under pressure until the glue is dry.

270. Red sealing wax makes a good electrical cement; sealing wax dissolved in naphtha may be used. Solutions of India-rubber in the several solvents are used as cements, particularly when required to be flexible. If India-rubber be heated to 398° F., so that it begin to fume and remain permanently viscid, it forms a drying cement with its own weight of a mixture of slaked lime and red lead in equal parts. For very delicate work solution of gelatine and mastic in rectified spirit or ether are the best cements, but requiring great care in preparation they are best purchased ready-made. Diamond cement is a cement of this kind used to cement metals, ivory, wood, glass, &c.; it is probably the best of cementing materials. The prepared cements for delicate work offered for sale do not always fulfil the promises set forth on their labels; for important work these should never be used until their value has been tested.

Section V.—*Concrete, Bèton, and Asphalt.*

271. Concrete is a mixture of mortar and small angular stones or gravel; the usual proportions by volume average about 1 part lime, 2 sand, and 4 small angular stones, or 1 part lime to 6 parts unscreened gravel. Where gravel or stones are not available, broken bricks or burnt clay may be used with advantage. The lime is mixed with the other ingredients and slaked after mixture, consequently the concrete expands as the lime slakes; this expansion amounts to about three-eighths of an inch in a foot, and it continues insensibly for a month after mixture. If the lime be slaked before use, the concrete contracts in setting about one-sixth of its volume when first laid and rammed. On mixture of the materials, the reduction of volume due to mixture varies from one-fourth to one-third the volume of the unmixed materials.

272. Bèton differs from concrete in being made with strongly hydraulic lime or cement instead of with fat lime, and as these materials slake with difficulty when mixed they are invariably slaked before mixture. The stones should not exceed two inches in diameter; the proportion of mortar to stones should be such as to rather more than fill the interstices between the latter, a quantity which varies in practice from one-half to once the

volume of stones. Fat lime and pozzolana may be used instead of hydraulic lime or cement. Bèton is used in situations exposed to the action of water, and commonly for foundations under water; but while setting it should be protected from the action of water in motion, which has a tendency to wash out the lime.

273. Concrete being made with fat lime does not set under water. Concrete and bèton are much cheaper than masonry and brickwork, requiring merely unskilled labour, and consisting in great part of much cheaper materials; but they have a tenacity only slightly above that of the mortar to which is due their solidity. They are usually used for foundations, although both in ancient and modern times they have been used for entire buildings, but such employment in modern practice is exceptional; they may, however, be employed for floors and roofs, are commonly so employed in India, and, under exceptional circumstances, they may be used for walls; for all such purposes bèton, because greatly superior in strength, should be preferred.

274. Concrete for foundations should be put into the foundation trench as soon as prepared, it should cover the whole of the bottom of the pit, and be well rammed, particularly round the sides and in the corners; it should be completed in layers not exceeding a foot thick, and as soon as set the building may be commenced on it. Bèton when used under water is thrown in in bags or a framework of timber, or fascines are used to protect it from the action of the water until set; sometimes it is moulded into blocks and thrown into water, or built up as blocks of natural stone. A bed of concrete covered with asphalt (as described below) forms an excellent flooring or roof, impervious to damp. Concrete may be used above ground in situations where the constituent small stones are not liable to be disturbed.

275. Asphalt is a bituminous limestone, containing from 3 to 15 per cent. of bitumen; it is found in the Jura mountains, in Trinidad, and other places. The composition of the bitumen is 85 C. 12 H. 3 O. per cent., it has a characteristic odour resembling that of tar and pitch, and strongest at the boiling temperature. Below 50° F. it is brittle, at 50° to 70° soft and plastic, 70° to 90° pasty, and above 120° liquid.

276. Asphalt ground to powder or broken small, with from $\frac{1}{7}$ to $\frac{1}{8}$ of its bulk of melted bitumen or mineral tar obtained from bituminous shale or sandstone, forms asphaltic mastic; the mass is thoroughly melted and the ingredients well incorporated. This compound, mixed with 15 per cent. of fine grit, is used as a covering for roofs, and with 25 per cent. of coarse grit it forms a good material for footpaths. The quantity of bitumen required is greater the less of it is contained in the asphalt; the addition

of the grit prevents the softening—pavements should not become appreciably soft at 160° F. Artificial or factitious asphaltic mastic is made by adding powdered limestone to either melted coal-tar or a solution of pitch in pitch oil; these artificial compounds are deficient in strength, but they are suitable for pavements in some situations, and are exceedingly cheap. One part of asphaltic mastic with about a thirty-fifth of resin oil, and three-fifths of sand, by measure, forms a bituminous or asphaltic mortar; eleven measures of this mortar with nine of broken stone forms a bituminous concrete, which may be used to cover roads and build under water. A layer of asphalt $\frac{3}{8}$-inch thick is impervious to moisture; good asphalt $\frac{3}{4}$-inch thick over a thick bed of concrete forms a good roof, and as pavement asphalt is very durable, being elastic and therefore less liable to crack than cement.

277. Asphalt requires but little skill to apply, and is easily repaired; with the addition of a little mineral tar old material can be worked up anew—although it softens it never takes fire. It has the disadvantage of not adhering well, and is hence unsuited to vertical surfaces, for the same reason it is liable to slip in summer if applied to steep roofs; as a cement for masonry it is dearer than Portland cement, and damp readily condenses on its surface. Asphalt is sometimes used to protect concrete from the action of water, it may be used to protect wood and generally to exclude water; it forms excellent pavements for battery rooms, particularly when under ground; used over felt it forms an excellent light roof for temporary buildings, and it may be used over iron sheds to exclude the sun's heat; its valuable properties might render it of great use in telegraph construction, particularly where skilled labour cannot be obtained; possibly it might be used to protect gutta-percha covered underground wires from the rapid deterioration they suffer in tropical climates. Subterranean lines of uncovered wire imbedded in asphalt were tried in France; they worked well without repair for five years, after which period they were still perfectly preserved. The wires were galvanised iron in series of 4, 6, or 10, in two parallel layers; they were four millimetres in diameter, and the distance between them and between the outside wires and the exterior surface of the asphalt was 27 mm. The asphalt employed was of the best quality. The composition of the concrete was in a hundred parts:—

Asphalt, ...	58·75
Purified bitumen, ...	7·24
Fine gravel, screened and well-washed,	34·01
	100·00

The cost per metre run, exclusive of the cost of digging the trench, was for ten wires 6 francs 65c., six wires 4 francs 77c., four wires 4 francs 42c. This mode of protecting wires has been abandoned, but for reasons apart from its efficiency. With due precautions asphalt may be used to protect underground wires in towns, between cables and land lines, etc., and in some situations prove efficient and economical. Asphaltic mastic may be purchased ready for use and packed in barrels, of the several asphalt companies; the quantities of grit to be added, mode of application, melting point, etc., of each preparation may be obtained from the vendors. A vessel in which to melt and mix the ingredients, and shovels or trowels to spread the mixture, are all required to enable unskilled labourers to execute most kinds of useful work; pavements and other surfaces required to be level are generally smoothed with an iron tool having a flat surface—it is attached to a wooden handle and used hot.

278. The limestone contained in asphalt may be attacked by strong acids; a mixture of coal tar and finely-ground fire-clay in such proportions that when cold the mixture yields perceptibly to the nail, forms an excellent material for stopping joints in pipes and other vessels to contain corrosive liquids. The so-called asphalt used with hemp for covering telegraph cables does not appear to contain asphalt; it differs in composition with different manufacturers, and consists principally of silica and bitumen or mineral tar; "Clark's Compound" or "Clark's Asphalt" is composed of by weight "65 parts of mineral pitch, 30 parts of silica, 5 parts of tar" (Clark & Sabine); the term "silicated" used by some manufacturers is evidently better than "asphalted" as applied to such preparations. Mixtures of silica and bitumen are cheaper than asphalt, and quite as well if not better suited to protect the hemp of a cable from the attacks of marine animals, and the wire-covering from oxidation.

SECTION VI.—*Masonry and Brickwork.*

279. The following are the common technical terms used in describing masonry and brickwork:—The surface of the work exposed to view is termed its *face*, the face of each block is its surface exposed on the face of the work; if one *end* of a block appear on the face of the work so that the length of the block be perpendicular to the face of the work, this block is termed a *header*, the face end is sometimes termed the head, and the back part extending into the work the *tail;* a block lying with its length parallel to the face of the work is termed a *stretcher.* When the work is built up in layers, each layer successively forming a

plane surface on which the next is built, these layers are termed courses, and the work is said to be *coursed;* when the courses are not made of uniform depth one with another, and at the same level throughout their whole extent, the work is said to be built in *random* courses. The surfaces of a block parallel to the courses are termed its *beds,* and the joints between or parallel to the courses are termed *beds* or *bed-joints;* the joints transverse to both the beds and the face are termed *side*-joints or simply joints. Corner stones are headers on one face of the building and stretchers on the other; they are usually larger than the other stones, selected, and are termed *quoins.* A course of large stones projecting somewhat beyond the face of the structure, usually serving to distribute a load over the smaller stones of the course below, is termed a *string course.* A course placed on the top of a wall to protect it from rain and prevent the course below being disturbed by violence, is termed a *cope;* it may consist of large flat stones projecting beyond the course below, of bricks similarly projecting or not, or of stones placed on edge fixed with hydraulic mortar or cement; the cheapest kinds of masonry may be coped with sods or clay puddle. The first courses laid on the foundation are usually extended to distribute the pressure of the structure over an increased area, and thereby increase the stability of the structure; such courses are termed *footing courses,* and together form what is termed the *footing;* they are usually built to form a series of steps on each face, the uppermost course projecting least.

280. The following rules should be observed in building masonry and brickwork; they are applicable to all such work whether built with puddle, mortar, cement, or without cementing materials, of shaped or irregular masses of stone, or of bricks burnt or sun-dried. As far as possible the work should be erected in a series of layers or courses as nearly as practicable perpendicular to the load to be borne; the blocks should break joint with each other in the direction of the pressure, each block overlapping the joints above and below it so as to tie the work longitudinally; the amount of the overlap in masonry is from once to once and a half the depth of a course, in brickwork from a quarter to half a brick. The blocks should also break joint in the direction of the thickness of the work; or a certain proportion of them, termed in masonry bond stones, should pass transversely through the work or penetrate to a certain distance into it, to bind it in this direction; particular care should be taken in this respect at the corners where two walls meet at an angle. In masonry at least one-fourth of the face of the work should be headers. If the blocks differ in size the largest should be used for the lowest

courses. The shapes of the blocks should be such that they be not liable to be broken across; thus weak soft stones should not have a length greater than three times, nor a breadth greater than from once and a half to twice their depth; in harder materials the length may be four to five times, and the width three times the depth. Stones which have a laminated structure should be laid so that the direction of the principal pressure may be perpendicular or nearly so to the planes of the layers—this is termed laying the stone on its natural bed; it is also necessary that the beds of such blocks be their largest surfaces. When the blocks are not rectangular in shape but irregular, no side joint should make an angle with a bed joint less than 60°, and rounded stones should be broken into angular pieces. When mortar or similar cementing material is used the conditions stated in Paragraph 263 should be fulfilled; and as in such cases slight settlement occurs by reason of the compression and contraction or expansion of the cementing matter in setting, this settlement should not vary in amount in adjacent parts of the structure—*e.g.*, if the settlement be greater on one side of a wall than on the other by reason of the joints being more numerous, thicker, or filled with different material, the difference of settlement may cause the wall to lean to one side, or to crack longitudinally; and inequality of settlement in contiguous parts in the direction of the length of the work causes vertical cracks, the injury being more certain the greater the height of the structure and the difference of settlement. The back joints of the facing blocks in footing courses should be as far back as practicable, and far enough to fall vertically under the superstructure; the projection outward of each footing course beyond the course above should be smaller the greater the weight to be borne, and the projection both of each course and the whole footing must be such in proportion to the depth in each case respectively, that there may be no danger of the projection being broken off by the weight of the structure and slight settlement of the foundation.

281. Stones are shaped and faced by means of a hammer termed a scabbling hammer, the head of which is pointed on one side and axe-shaped on the other; and chisels, one pointed, the others of various widths. The hammer produces an approximate plane surface; its point leaves a surface covered with small parallel ridges, the chisel cuts away these ridges and leaves a plane surface. Stone dressed with the hammer is said to be *scabbled*, smoothed with the chisel it is said to be *droved*.

282. Masonry is of an indefinite number of qualities, depending on the regularity of form and degree of finish given to each stone, the size of the blocks, &c., and frequently different quali-

ties are mixed in the same structure; thus, a structure in which pressure is more concentrated on one part than another may have a better quality of masonry where the pressure is greatest. The superior qualities are used also to strengthen parts of inferior masonry, as the angles where walls meet, and for the sake of appearance and durability inferior may be faced with superior. ASHLAR masonry is composed of regular blocks built in courses of a uniform depth, seldom less than a foot. The best kinds have the stones dressed with the chisel, the coarser kinds with the hammer. The faces may be dressed or even quarry-faced, but the beds and sides of the blocks are dressed accurately; in the case of the beds this is of great importance, in order to distribute the pressure over the whole surface of the bed of each block. BLOCK-IN-COURSE masonry differs from hammer-dressed ashlar chiefly in being built of smaller stones. COURSED RUBBLE masonry is built in courses generally less than a foot deep; the side joints are not necessarily vertical, but each course is correctly levelled to form a base for the succeeding course. COMMON RUBBLE differs from the above in not being coursed. DRY STONE building is the same as coursed or common rubble, with the mortar omitted. Clay puddle may be used to cement stones built as in common or coursed rubble; this work forms a durable base to a mud wall, and an excellent facing to earthwork, when sheltered. Ashlar masonry is used for work in which the greatest strength, durability, and finish are required; it is used for quoins, copes, and string courses of brickwork, and inferior kinds of masonry. Ashlar and block-in-course are frequently backed with rubble.

283. The systematic arrangement of the blocks, to which is due in a great measure the longitudinal and transverse tenacity of the work, is termed the bond. The strongest bond when the blocks are regular in shape and uniform in size and figure, as is the case with bricks, is that in which each course is composed of a header and a stretcher alternately on the face of the work, the headers of each course being over the centres of the stretchers of the course below; in this case somewhat more than one-third of the area of the face consists of the ends of headers; in general the ends of headers should compose at least one-fourth of the area of the face. These headers should penetrate quite through the work if thin, and for a distance equal to three to five times the depth of the courses if thick. When the stones are irregular headers should range in breadth from once and a half to twice the depth of the course; and they should be the entire depth of the course, although, as in rubble, the other stones may be smaller, and two or more to the depth of the course.

284. When the stones are shaped to fit well together, as in ashlar

masonry, the mortar should be about one-eighth of an inch thick, and its volume about one-eighth that of the stone employed; in rubble the volume of mortar reaches one-fourth that of the stone. In building rubble spaces between the larger stones should be filled with smaller stones, not with the cementing material only.

285. If superior kinds of masonry be backed by inferior kinds, the face and backing should be carried up together in courses of the same depth, the two kinds should be held together by headers of the superior masonry extending into the backing; these headers should be properly proportioned both as to number and penetration inwards, they may taper in width in the backing but not in depth, and the facing stones should be dressed and fitted as superior masonry for a certain distance inwards, generally from once to twice the depth of a course. Blocks of stone in masonry are sometimes fitted together with cramps or dowels fixed with lead or cement; insulator brackets and stalks are often fixed into masonry either in the joints or in holes cut in the stones—cast iron should be used generally, as wrought iron is more liable to corrode, when it swells and may open the joint or split the stone. Cope stones and others requiring extra strength are sometimes fitted together with dowels; these are small pieces of iron, copper, or hard stone, fitted into contiguous holes in adjacent stones with lead or cement, serving thus to connect the stones together; hard stone dowels are the most durable; if iron be used cast iron should be preferred. Dry stone masonry 6 to 18 inches thick is used to protect earthen slopes against the action of water, the beds of the courses are laid perpendicular to the slope; it is also used for low walls. In places where the ground is rocky and there is not sufficient depth of surface soil in which to fix line posts, cairns of dry stone are built in which the posts are set, the interstices between the larger stones are filled with surface soil and small stones, and the whole is coped with sods, surface soil, or clay puddle; in such cases, if the surface soil will admit of it, an earthen mound faced with dry stonework or stone set in mud may be used; in any case the durability and strength of the work will depend on the observance of the rules as to bond, &c., stated above. Where the ground is very rocky or very loose posts are sometimes built into plinths of coarse masonry set in mortar or cement; this is sometimes necessary also in the case of masts erected in waterways, stays not being admissible, as they catch driftwood. Great care is necessary in erecting such plinths, as the vibration of the wire and post often so interferes with the setting of the mortar that the stones work loose, and a force acting at the summit of the post acts with great leverage

to disturb the masonry; it is safer to use hydraulic mortar, and time should be allowed for the mortar to become solidified before placing the wires on the posts. Such short pillars should be coped with large flat stones, and excepting when very low they should taper upwards; the mass necessary to give the required stability and the tensile strength should be calculated in each case. Poles injected with sulphate of copper are better set in plaster than mortar, as chemical action occurs between the lime in the mortar and the sulphate of copper in the timber. Masonry obelisks are in some cases cheaper than timber or iron to suspend lines over rivers; these should be of rough block in coarse masonry, they should be well spread out at the foundation, which should be placed below the surface to a depth sufficient to ensure permanent stability of the soil below. Large stones are seized for hoisting by claws or nippers, by two short plugs inserted in holes and attached to a chain, or by an instrument termed a *lewis*.

286. In constructing brickwork, as the blocks are uniform in size it is comparatively easy to ensure the observance of those rules on which the strength and stability of blockwork structures depend (Paragraph 280); but in the case of coarse masonry, as rubble and dry stone building, great watchfulness is sometimes necessary to prevent the work being badly done. In brickwork the only conditions to observe besides those already stated are—to reject all misshapen and unsound bricks, and to guard against the use of *bats* or pieces of bricks, excepting when absolutely necessary to close an opening or finish the end or corner of a wall; in no case should less than half a brick be used. Where possible the dimensions of the work should be such as to render bats unnecessary, and care in correctly building the bond selected should be insisted on, that the use of bats be not rendered necessary by careless workmanship.

287. Brickwork is built in courses consisting entirely of headers and entirely of stretchers, a course of headers alternating with one, two, or more courses of stretchers, fig. 59, or in courses

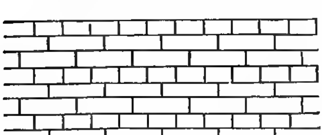


Fig. 59.

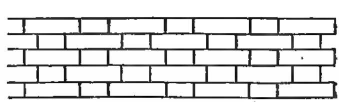


Fig. 60.

in which headers and stretchers alternate in each course, fig. 60; the former system is termed *English bond*, the latter *Flemish bond*.

In English bond the length of a brick being twice its width, there are twice as many side joints in a course of headers as in a course of stretchers; and unless great care be taken to keep these joints thin in the header course the equality of the courses will not be maintained, and the use of bats will be rendered necessary; but English bond is esteemed stronger than Flemish. The proportion of headers and stretchers in English bond should be regulated accordingly as longitudinal or transverse tenacity are the more desirable; one course of headers to two of stretchers, fig. 59, produces equal tenacity in both directions; when the longitudinal tenacity is of more importance than the transverse, as in plinths for posts, as many as three or four courses of stretchers may be used to one of headers. Flemish bond is neater in appearance than English, and as the courses are alike, containing both headers and stretchers, the number of side joints in each course is the same; hence there is no danger of the equality of the courses being lost. The longitudinal tenacity of brickwork is sometimes increased by pieces of hoop iron laid in the bed joints, these should break joint with each other, and the ends of each piece should be secured by being bent down at a right angle and inserted into side joints. String courses and copes of bricks should consist entirely of headers; the outsides of footing courses should also be all headers, no course projecting more than a quarter of a brick beyond the course above it, excepting in walls too thin to render this condition possible; the object of using headers is to keep the back joints as far back as possible and under the superstructure. In exceptional cases footing courses are laid double, a header course being laid above a stretcher course, or a single course of stretchers is laid as a lowest course.

288. Stone coping is commonly used with brickwork, of which it increases the durability, brick copings being liable to have the bricks disturbed; the use of stone coping string courses and quoins with brickwork increases its strength and stability. Great care is necessary when stone quoins are used, as the joints in the brickwork being more numerous than in the stonework, there is danger of unequal settlement; to prevent this the joints between the courses of bricks should be made as thin as possible. Flat cope-stones should be cramped together or connected by dowels as a means of greatly increasing the durability of the work, particularly in circumstances where they may be subjected to accidental violence tending to disturb them.

289. Masonry and brickwork is best estimated for in telegraph estimates by the cubic yard, local and trade measures should be expressed in this unit. The work of building in stone and brick such structures as are required in telegraphy is so affected by the peculiar circumstances of the case, that data furnished by ordinary

buildings are of but little use, in general strict supervision alone can secure due economy: telegraph work is enhanced in cost by being distributed over considerable distances, by consisting of small structures, and by the different and generally low degrees of efficiency of the workmen employed. The following data are given on the authority of Professor Rankine:—Exclusive of mixing mortar, building dry stone, coursed rubble, or block in course, one man per cubic yard per day; ashlar one-half to one cubic yard per man. The labourer's work and labour of stone breaking must differ greatly in amount, according to the circumstances of each particular case: dry stone building will require one man, coursed rubble one and a half man, and block in course about two men per cubic yard; ashlar requires more on account of the extra stone breaking and size of the stones. Stone cutting for block in course requires about one and a half man per cubic yard, ashlar from two and a half to six men. The above refer to soft stone. Hard stones require three to four times the labour to cut required by soft sandstone. In brickwork a bricklayer and labourer are said to build about 1·6 cubic yard per day.

290. The strength of the highest class masonry is inferior to that of the single blocks of which it is built (Paragraph 71). Coursed rubble offers about four-tenths the resistance to crushing offered by the single blocks composing it; common rubble is but little stronger in this respect than the mortar employed; hence, if strength be required, rubble masonry is rendered suitable by the use of strong hydraulic mortar. The ultimate resistance to crushing of good hand-made bricks is 800 to 1000 lbs. per square inch; that of inferior kinds may be as low as half this; and ill-burnt hand-made bricks may offer an ultimate resistance to crushing but little over 200 lbs. per square inch. A machine-made brick by Messrs. Clayton and Co., tested by Mr. Kirkaldy, offered the extraordinary ultimate resistance to crushing of upwards of 5,000 lbs. per square inch, the greatest resistance attained; other machine-made bricks, by the same makers, bore 1,478 lbs. per square inch without cracking, 2,068 lbs. before cracking considerably, and nearly 3,000 lbs. before being quite crushed. The experiments of Mr. Clarke gave 5,200 lbs. as the resistance of rather soft bricks set in cement, and this is about the average resistance offered by ordinary stock bricks set in good mortar. The subject of the tensile and transverse strength of brickwork and masonry has not received so much attention as their resistance to crushing; for in the majority of cases, the resistance to crushing and the stability are relied on, and the tenacity and transverse resistance are not called into play; but it has been pointed out with justice, that although sometimes

ignored in theory, in practice the tenacity of brickwork is commonly applied in practice, and in many cases of flat brick arches and beams bearing walls, the brickwork acts as a beam. The tenacities of mortars and cements are stated in Section 3. The tenacity of good bricks is on an average 270 to 300 lbs. per square inch (Rankine); M. Morin states it 277 lbs. In green brickwork the strength and adhesion of the cementing material determines the strength of the work, but when the cementing material has set, it may be stronger than the bricks. The transverse strength and tenacity of brickwork are probably sensibly equal, and depend on the strength of the bricks and cement and the adhesion between them. The tenacity of each kind of cementing material is stated in Section 3. The adhesion of common mortar to compact limestone is 15 lbs. per square inch, to brick 33 lbs., six months after mixture (Rondelet). Mr. Robertson found the adhesion of well-ground mortar of the same age was—to blue stock bricks, 40 lbs., and to grey stocks, 36 lbs. per square inch. General Pasley found the adhesion of cement to stone was as high as 125 lbs. per square inch when quite hardened; he found the average adhesion of two bricks cemented together with Portland cement to be 140 lbs. per square inch; in the interior of thick joints it is probably much less. Vicat considered the adhesion of mortar to bricks equal to the tenacity of the cementing material (Paragraphs 259 to 262). Mr. Robertson found the adhesion of cement to grey stock bricks to be as follows:—

				Lbs. per Square Inch.
Quick	setting	cement,	1st week,	23
„	„	„	4th „	30
Slow	„	„	1st „	15
„	„	„	4th „	59

See also Paragraphs 259 to 262. Some of the above data are from articles on the tensile and transverse strength of brickwork and masonry which appeared in *Engineering* in 1872. The factors of safety for brickwork and masonry are 8 to 10 for a live load, and 4 to 5 for a dead load.

291. The durability of masonry and brickwork built with common or slightly hydraulic mortar, is increased by pointing, the mortar being scraped from the outer edges of the joints with the point of a trowel, the groove so formed is filled with hydraulic mortar or mixed cement to protect the interior mortar.

292. When inserting posts or brackets in, or supporting posts on, masonry or brickwork, the fact that the tensile strength of such work is comparatively low should not be lost sight of; thus

masonry erected to support a post where the soil is too shallow to insert the post in the ordinary way, should be of a weight proportionate to the pull on the post, and should be well bonded, particularly at the corners. If a bracket be inserted in a wall, it should be considered if the weight of the wall above the point of insertion of the bracket and its tenacity be sufficient to resist the action of the bracket when loaded, if this weight be insufficient, as when a bracket inserted near the top of a wall has to carry a post or other heavy load, then the outer end of the bracket should be supported by an oblique strut resting on a string course or other projection, or inserted into the wall below, thus transferring the tension on the wall to a point sufficiently low to ensure the requisite stability, or preventing tension entirely. To insert a cantilever in a wall, it is merely necessary to cut a hole in the wall and insert the cantilever, using cement or plaster; iron to be inserted in a hole in a stone may be fixed by means of melted lead, the advantage of this mode of fixture being the preservation of the iron from destruction at the joint by oxidation, and preventing it from splitting the stone by its expansion.

CHAPTER II.

METALS AND ALLOYS.

SECTION I.—*Iron*. DIVISION I.—CAST IRON.

293. PURE iron is only known in the laboratory; the iron commonly used is combined chemically and mechanically with other substances. The chemical equivalents of iron are 56 and 28 ($H = 1$); deposited by electricity its specific gravity is 8·14. It has a brilliant lustre, takes a high polish when burnished, is soft, has a great affinity for oxygen, is rapidly dissolved in acids, and therefore is easily tarnished; alkalies protect it from corrosion. Carbon and iron are the only essential ingredients in cast iron, steel, and wrought iron; on the proportion of carbon present depends those distinguishing characteristics on which the classification is based. Wrought iron is iron containing not more than 0·25 per cent. of carbon, steel contains more than 0·25 and less than 1·9 per cent., cast iron contains more than 1·9 per cent. These distinctions are in a measure arbitrary, cast iron, steel, and wrought iron merging into each other without any defined

line to mark the distinction; thus, according to some authors, steel has from 0·5 to 1·5 per cent. of carbon, compounds containing from 0·25 to 0·5 per cent. are termed steely iron or semi-steel, and those containing from 1·5 to 2 per cent. are regarded as intermediate between steel and cast iron; but the justice of the former classification will be apparent after consideration of the distinctive qualities of the several compounds named. Cast iron can be neither forged, welded, nor drawn.

294. Iron is found nearly pure, as in meteoric iron, which consists of from 85 to 90 per cent. of iron combined with other matters, principally nickle and cobalt. Commercial iron is obtained from ores consisting of the oxides or carbonate combined with various other substances, principally clay and sand, with smaller quantities of the carbonates of lime and magnesia, and still smaller quantities of carbon, manganese, arsenic, &c. Ores containing at least 20 per cent. of iron are termed ores proper, as they can be profitably smelted alone. Ores containing a smaller proportion of iron are termed fluxes; they are used with the richer ores to supply the deficiency of clay or sand necessary to aid as a flux in smelting, the addition of poorer ore being more profitable than the addition of simply those matters required to complete the formation of the required flux. If the iron is in the form of carbonate (otherwise rarely), the ore is roasted to expel carbonic acid and water, a small quantity of the sulphur is expelled, and organic matters, if present, are decomposed. The ore is mixed with fuel and a flux usually containing lime, the proportions of the ingredients of the mixture being determined by experiment or analysis for each description of ore. The mixture is placed in a furnace urged by a powerful blast of hot or cold air, the oxygen of the air combines with the carbon of the fuel to form carbonic acid; this is decomposed by the heat into carbonic oxide and oxygen, the oxygen of the iron combines with the carbonic oxide to re-form carbonic acid; the limestone is decomposed, the lime combines with the earthy matter of the ore to form a glass or slag. The molten metal reduced sinks to the bottom of the furnace, and the slag floats on the top of it; when the process is completed the iron is run out and cast into ingots termed pigs. Sometimes the iron is run directly into moulds to form castings, but this practice is only employed for inferior work; when considerable strength is required the iron is cast into pigs, and the best of these are selected for remelting. In some cases common salt or other chloride is used to remove sulphur and phosphorus. On an average about 6 tons of ore, fuel, and flux, and 13 tons of air are placed in the furnace for each ton of iron obtained, yielding about 3 tons of liquid, and

nearly 16 tons of gaseous matter. The proportions of ore, flux, and fuel, the kinds of flux and fuel, the strength and temperature of the blast, and other details, depend on the quality of the ore and kind of product required; these matters require considerable experience in the smelter.

295. Iron obtained from the blast furnace is very impure; it contains 2 to 5 per cent. of carbon, besides silicon, sulphur, phosphorus, manganese, calcium, and magnesium. The presence of carbon is essential to fusibility; manganese makes iron harder, and it improves the quality of steel, but in large quantities it diminishes the tenacity; its presence is not essential to good steel. Sulphur, calcium, and magnesium make malleable iron *red short*, or brittle at high temperatures; phosphorus and silicon make it *cold short*, or brittle when cold. Sulphur is derived from the fuel, hence the superiority in this respect of iron smelted with charcoal; phosphorus is derived from the flux or the fuel—the removal of these is effected by chlorides. The presence of the metals derived from the lime and earthy matters cannot be prevented, because if either lime or silica be absent, the other must be added as a flux.

296. Cast iron is distinguished as *white* and *grey*: these do not differ in the quantity of carbon they contain, but in the manner in which the carbon and iron are combined; white cast iron contains 2 to 4 per cent. of carbon combined chemically, the grey iron contains only 1 per cent. or even less combined chemically, the remainder being mixed mechanically. The production of white or grey iron is determined by the management of the furnace; a high temperature and abundance of fuel produces grey iron, a lower temperature and less fuel white iron. Grey cast iron is bluish in colour, granular in texture, comparatively soft and fusible, and weaker and more fluid when fused than the harder variety. White iron is distinguished as granular and crystalline; the former is convertible into grey iron by fusion and slow cooling, and reconverted by refusion and sudden cooling, these changes occurring more readily in iron of good quality. White iron is white, brittle, excessively hard, infusible, strong, less liable to rust, less soluble in acids, and employed as bearings has less friction than the grey; the crystalline variety is the harder and more brittle, and is therefore unsuited to engineering purposes. Grey iron is distinguished by number accordingly as it differs more or less from the white, No. 1 being that furthest removed—*i.e.*, the softest, most fusible, &c. Granular white cast iron is also too brittle for use alone in engineering structures, but it is used with grey iron; when grey iron is cast the outer layer of the casting is cooled quicker

than the inner parts, and it forms a skin approaching more nearly than the interior to the condition of white iron. The white condition of the skin is ensured for some purposes by the process termed *chilling*, which consists in lining portions of the mould with suitably shaped pieces of cold iron; the molten metal being suddenly cooled by contact with the cold iron, the casting is covered to from one-eighth to one-half inch in depth at these parts with white iron, the remainder of the casting retaining the grey condition. The skin of cast iron is harder and stronger than the interior, it contributes greatly to the strength of the casting, and it should not be injured or cut in any part to suffer considerable stress. As cast iron varies between the extremes of the very hard strong and brittle white, and the comparatively soft and weak No. 1 grey, in any particular case that quality best suited to the purpose should be selected. Grey cast iron No. 1 is most fusible, it produces the most accurate castings, but it is soft and deficient in strength; it is suitable for small castings in which accuracy is more important than strength, and in which it is especially required to attain the minimum brittleness. In large castings for engineering works the extreme brittleness of the white, and the softness and weakness of the No. 1 grey, are both undesirable; a quality intermediate between these extremes should be selected—Nos. 2 and 3 grey are best suited to these purposes. The qualities of iron are also distinguished by the name of the place or district where made, and mixtures of these several qualities are sometimes superior to either quality separately; various mixtures are sometimes prescribed when iron of particularly good quality is required, but the telegraph engineer seldom if ever requires very large castings, and in any case it is as a rule better to state the degree of excellence required, and test the iron actually supplied, leaving the attainment of the result to the smelter or founder. The use of the hot blast economises fuel, but affects in a marked degree the properties of the product; the most usual temperature for the blast is 600° to 700° F., it is often 1000° F., and has exceeded 1500° F. The quality of iron smelted with the hot blast is on an average about the same as that smelted with the cold blast; No. 2 hot and cold blast are about equally good, but No. 1 cold blast and No. 3 hot blast are superior to No. 1 hot and No. 3 cold respectively, the ore and fuel being the same in both cases. The quality of cast iron is improved up to a certain point by repeated fusion, and by being kept in a state of fusion; Sir W. Fairbairn's experiments shewed an increase of transverse strength up to the twelfth melting, the bars were one inch square in section, and about four feet long;

the breaking weight at the commencement was 403 lbs., after the twelfth melting it was 725 lbs., after the thirteenth 671 lbs., after the fifteenth 391 lbs., and after the seventeenth only 330 lbs.; when fractured the metal appeared changed, resembled in fracture cast steel, and its resistance to pressure had doubled. Iron after half an hour's fusion had a tenacity of 17,843 lbs. per square inch, and a density of 7·187; the same iron kept in fusion two hours had a tenacity of 34,496 lbs., and a density of 7·279. The results of some experiments made in America were: the tensile strength was raised from 14,000 lbs. and 11,000 lbs. per square inch, to 35,786 and 45,970 lbs. respectively, by three meltings—the degree of improvement doubtless depends on the composition of the iron. Other processes are employed to improve the quality of the iron for particular purposes—TOUGHENED CAST IRON is made by mixing with ordinary cast iron from one-fourth to one-seventh of its weight of scrap iron. MALLEABLE CAST IRON is made by heating castings made in the ordinary way, but preferably of certain qualities of iron, in contact with a ground hæmatite ore pounded iron stone, smithy scales or other similar substance which absorbs carbon; the castings are embedded in the powder, gradually raised to a bright red heat, kept heated, and then gradually cooled. Powdered hæmatite is usually preferred; the process takes twenty-four hours to raise the temperature, twenty-four hours to cool the furnace, and the heat is maintained three to five days: the thinner castings are converted quite through, the thicker for some depth; the tenacity is said to exceed 48,000 lbs. per square inch, and the thinner castings can be bent and torn. The iron is converted into a soft kind of steel, but has not the strength of malleable iron, by reason of the absence of fibre given to the latter by rolling, hammering, &c.; these malleable castings are used very extensively for post fittings, their only disadvantage, as compared with soft cast-iron castings, is their greater cost.

297. Although repeated fusion is beneficial the metal is seldom in practice melted more than thrice, and in the majority of cases only twice. Common rough articles are cast in open sand moulds, but when the casting is required to be strong it is cast vertically, under pressure, and with a head, which is broken off when cooled. The head contains any air bubbles present, and by casting under pressure the iron fills the mould better and its density and tenacity are increased. An experiment on the comparative density and tenacity of rough pigs cast horizontally, and a moulded bar cast vertically gave the following results:—

	Tenacity.	Density.
Rough pigs cast horizontally,	14,481	7·004
Bar cast vertically, . . .	16,424	7·085

Different qualities of iron shrink differently in cooling, castings should therefore be of uniform quality throughout; when this is not the case the surface of the casting is uneven, and it is inferior in strength. The shrinkage in cooling from the melting point is on an average about $\frac{1}{96}$ in each dimension, or $\frac{1}{8}$-inch per foot, and patterns have to be made larger than the object required in this proportion. If castings be cooled suddenly they are rendered brittle and sometimes break spontaneously before leaving the foundry; hence to avoid unsafeness from internal stress castings should not be removed from the moulds until cooled to within a few degrees of the temperature of the air, and open sand castings should be covered with sand to hinder too rapid radiation. Great inequalities of thickness should be avoided in designing, in order to ensure that each part shall cool at the same rate; when the rate of cooling has been unequal at different parts, thus causing internal stress, the iron is said to be *hide bound.* Annealing has the same effect as slow cooling, provided the heat be sufficiently intense to affect the cohesive force. Air bubbles are tested for by ringing the casting over its whole surface with a hammer.

298. The temperature of fusion varies with the quality of iron, and authorities differ widely; about 2,800° F. is accepted as an average for qualities of iron in common use. In experiments tried by Sir W. Fairbairn, No. 2 iron decreased and No. 3 increased in transverse strength up to 600° F.; the strength of No. 3 was reduced by one-third by raising the temperature to a red heat; below 32° F. cast iron is more brittle. The co-efficient of expansion for 1° F. at ordinary temperatures is ·00000617, and the expansion between 32° and 212° F. is ·00111.

299. The strength of cast iron is affected by the size of the casting; in thin castings the external portion is stronger than the interior, but in thick castings the rate of cooling being slower, the outer part is in a measure annealed, and this difference is less (unless chilling be resorted to); hence the tenacity, transverse strength, and density of thick castings is less than that of thin ones. If the iron be highly decarbonised, large castings have a tenacity nearly 5 per cent. above that of small castings, for in this case the skin has less value and the larger casting is more homogeneous. In consequence of the existence of the skin, the modulus of rupture in the same kind of iron differs in value accordingly as the bars be broken transversely as beams, or torn asunder as ties; the transverse strength differs with the form of

cross section from equality to about two and a quarter times the tenacity; for when strained transversely the intensity of stress is not uniform over the whole section, its maximum intensity is in parts of the skin, but the direct tenacity is obtained by a more uniformly distributed stress, the central and consequently the weakest matter suffering the more intense load. The ultimate tenacity of cast iron varies from little over 4 tons to rather more than 15 tons per square inch; average qualities offer a resistance of about 7 to $7\frac{1}{2}$ tons, inferior qualities as low as 5 tons, and for particular purposes, as for casting guns, 10 tons is the minimum tenacity admitted. Toughened cast iron has a tenacity varying between $10\frac{1}{2}$ and $11\frac{1}{2}$ tons. The resistance to pressure offered by cast iron varies between about 20 tons and nearly 65 tons per square inch; on an average in practice it is about 50 tons. The ratio between the tenacity and resistance to crushing in seventeen experiments tried by Mr. Hodgkinson varied between 1:6·7 and 1:4·5, the mean being 1:5·66; it will be seen on comparison of the figures given above that the average resistances to compression and to tension are not related in this ratio: from Mr. Hodgkinson's tables the ratio in the case of Coed-Talon No. 2 appears to have been 1:4·337, and for Carron No. 3, 1:8·473, the mean being 1:6·59; the specimens were not necessarily from the same sample in each case. It is evident this relation varies with the quality of the iron, in practice it is often assumed to be nearly 1:6. The transverse strength varies, as stated above, according to the size of the casting and the form of section; the ultimate load of a bar 1 inch square in section, supported on supports 1 foot apart, and loaded in the centre, varies between about 1800 lbs. and 2500 lbs. A simple approximate formula is:—A bar $1' \times 1'' \times 1''$ breaks with 1 ton in the centre, this is about the mean. Strained transversely the deflection varies with the quality; the deflection of hard white is to that of whitish grey as 1:1·5, and of hard white to soft grey as 1:2·224. The resistance to torsion is very variable, ranging from between 300 and 400 to 900 foot-pounds, the rod being cylindrical in section, the average may be assumed in practice as about 700 lbs.; a permanent set of half a degree is given with about seven-tenths of the ultimate load. The resistance to shearing is about 27,700 lbs. per square inch, it is sometimes stated as high as 32,500 lbs. The density of cast iron varies between 6·9 and 7·4, the average being about 7·11; a cubic foot weighs from 431 lbs. to 461 lbs., the average being about 444 lbs.; the strength and hardness increase generally with the specific gravity. The proof load is about one-third of the ultimate load. The usual factor of safety for bridges is 6; when

the load is entirely a dead one 4 may be used. Cast iron is superior to wrought iron in its resistance to crushing, and it is hence better suited for use as pillars and struts; with a limited load it suffers greater strain and set than wrought iron (Paragraph 313). Its modulus of elasticity varies between 14,000,000 and 22,900,000. Its modulus of resilience may be calculated from the above data by means of the formula given in Paragraph 57. It is inferior to wrought iron as bolts, rivets, &c., offering rather more than half the resistance of wrought iron to shearing; it is less suitable for use as ties than wrought iron, by reason of it being so inferior in tenacity. As pillars, cast iron is only superior to wrought iron when the length is so limited as compared with the diameter that there is little tendency to bend, and the effect of inferior tenacity is compensated by the superior resistance of the material to crushing; assuming the intensity of the ultimate resistance to crushing to be 80,000 lbs. per square inch, Professor Gordon has shewn—when the diameter of a pillar is $\frac{1}{26{\cdot}4}$ of its length, cast and wrought iron are equally strong, but in a proportionately longer pillar wrought iron, and a shorter one cast iron, would be the stronger respectively (Paragraphs 76 and 77). In telegraph poles cast iron is used for the base segments, for which it is better suited than wrought iron, as it is less liable to corrosion; it is used thicker than wrought iron from necessity to give sufficient strength, and such extra thickness is less costly than an equal thickness of wrought iron would be; as a rule, the base segments are far below the above limits of comparative length, even in the largest masts the cast iron basement tubes rarely exceed 24 feet, of which half is embedded in the ground. Long pillars of cast iron are used in towns, they are usually much stronger than requisite to carry the load, extra metal being used for the sake of appearance, but such pillars should be tapered to reduce their weight.

300. Cast iron for engineering purposes should be sounded for air bubbles, the skin should be continuous, the surface smooth, the edges sharp, and the iron soft enough to be indented when struck on an edge with a hammer; the fracture should be light bluish-grey, with a metallic lustre, and uniform in colour, excepting near the skin, where it may be lighter. If the fracture exhibit a mottled surface with patches of darker, lighter, or crystalline iron, the casting is not homogeneous and is unsafe; the texture should be uniform and close-grained. Cast iron is very generally used for brackets, caps or pole roofs, lightning dischargers, insulator hoods, and other fittings to wrought iron and wooden posts, for such purposes soft grey iron should be used, and cooled

very slowly or annealed; direct strength is as a rule more than provided for, and brittleness is to be feared. The iron used is as a rule soft, because it is only soft weak iron which is fluid enough to fill the moulds; but rapid cooling and faulty design has in some cases caused distrust of the material and led to its supercession by the more expensive material malleable cast iron. In castings, abrupt differences of thickness and sharp shoulders should be avoided, as the castings are rendered weaker thereby and fail as a rule at such parts. Malleable cast iron is used for fittings; from its greater strength it may be used in light hollow forms, and hence such malleable castings are much lighter than castings for the same purposes of ordinary cast iron.

301. Cast iron is less liable to corrosion than wrought iron, and the hard crystalline variety is more durable than softer qualities. Sea water corrodes cast iron and converts it into a black friable substance; the exterior surface of the skin is usually coated with silicate of the protoxide of iron, which protects the casting; this protection is less in chilled castings, but this is an additional reason for avoiding any rupture of continuity of the skin.

302. As cast iron varies so widely in quality, some means should be employed to ascertain the quality actually delivered by the contractor; the several means usually employed are as follows:—1. Test-bars are cast with the castings, and the transverse strength of these bars tested by experiment; 2. beams are tested by bending them under a weight or by hydraulic pressure, the load which bends them through $\frac{1}{480}$ of the span is assumed to be half their ultimate load; 3. a small percentage of surplus castings are ordered, and the surplus number taken at random are tested to fracture. When possible the third is the safest mode, for small articles the first may be the only mode admissible. With posts required in considerable number the third mode should be adopted; brackets &c., may be tested for brittleness by the hammer or file, or by letting a weight fall on them from varied heights, and by examination of the surface of fracture.

Division II.—Malleable Iron.

303. Malleable iron is the purest iron, its only essential constituent is iron, and it is in general higher in quality the nearer it approaches to pure iron; in practice it is never absolutely pure, it contains minute proportions of the impurities mentioned in Paragraph 295, and the carbon is never entirely eliminated. The kind of fuel used in refining and in smelting the cast iron influences the quality of wrought iron; iron smelted with char-

coal is purer than that smelted with coal or coke, by reason of the absence of impurities (particularly sulphur) derived from the fuel; but in England coal and coke are used in smelting almost exclusively, the supply of charcoal being too limited to admit of its use; hence, for steel making and for special purposes, purer charcoal iron is imported, principally from Norway, Sweden, and Russia. The specific gravity of malleable iron varies between 7·5 and 7·858, the nearer it approaches the latter value, the better its quality as a general rule; in practice it is usually nearer to the latter than to the former, and is commonly assumed as 7·68 or 7·69; in Mr. Kirkaldy's experiments the limits were 7·5 and 7·8; it is seldom less than 7·6. A cubic foot weighs from 468 to 490 lbs., and is on an average 480 lbs.; the last value is generally employed in practical calculations. Malleable iron differs from cast iron in heaviness, in being more or less fibrous in texture, comparatively infusible, superior in tenacity, and inferior in the resistance it offers to pressure. It cannot be melted and cast, but at a high temperature it softens, when it may be fashioned by forging, and two pieces brought together may be welded into one, provided the surfaces placed in contact are clean; by this property malleable iron is distinguished from most other metal, for as a rule metals when heated pass directly from the solid to the fluid state without assuming the soft condition necessary to admit of welding. Malleable iron is, as its name implies, malleable; it is ductile and tough, hence it is suited to resist shocks, and it does not fail without first exhibiting an alteration indicating that its elasticity has been overcome; the precise point at which it begins to yield under pressure is, with the softer varieties, very difficult to ascertain. It is softer than cast iron, and more liable to corrode. If highly heated and suddenly cooled it is rendered harder, its tenacity is increased, but it is rendered less suited to resist shocks, if very slowly cooled it is rendered softer; these effects are less the purer the iron, and considerable when the iron contains a relatively large proportion of carbon (nearly one quarter per cent). Malleable iron is manufactured from cast iron by processes having for their objects removal of the excess of carbon the latter material contains over that contained by the former, and a bestowal of a fibrous and homogeneous structure by working, as hammering, rolling, squeezing, &c. Much ingenuity and learning have been displayed in attempts to get rid of the other matters contained in cast iron, particularly those most prejudicial and most frequently present—viz., phosphorus and sulphur; but although these are in part eliminated by the processes actually employed, the only sure mode of preventing their presence and thus obtaining the highest degree of excellence in

the product, is to avoid the use of ores and fuel containing them as constituents.

304. The processes most generally employed for removing the carbon are the old process of *puddling*, and the Bessemer process; in both the carbon is oxidated by agitation of the melted metal in contact with air, the carbon of the cast iron combines with the oxygen, and leaves malleable iron, mixed with more or less oxide of iron and cinder, which are expelled from the mass by the after processes of working it at a high temperature. The cast iron used for conversion is white pig iron, termed forged pig, this variety being unsuited for castings. The process of puddling is divided into two processes—the first termed *refining*, the second *puddling;* these processes are carried on either in different furnaces, or in immediate succession in the same furnace, termed a *boiling furnace*, the operation in the latter case being termed *pig boiling.* The process of refining consists in the removal of a quantity of the carbon and earthy matter by the action of a blast of air forced through the melted metal, by which a portion of the iron and much of its contained carbon are oxidised; the metal is run into a shallow mould, water is thrown over it, which by oxidising another small portion of the iron assists in removing the impurities, the metal is stirred to assist the process, and the cinder floats on its surface. The refined metal when cooled is broken into pieces, placed in a reverberatory furnace, termed a *puddling furnace*, 4 or 5 cwts. of metal being treated at a time; the current of air acts on the surface of the metal only, the puddler continuously agitates it to expose successively different portions to the decarbonising action; when the greater portion of the impurities have been eliminated the metal thickens, its melting point being raised, a spongy mass of metal collects on the hooked bar used as a stirrer; this mass increases until sufficient has been collected to form a *ball* or *bloom*, this bloom is placed on one side and others collected, until from five to eight have been obtained; the yield is nearly 95 per cent. of the metal charged. The white hot balls from the puddling furnace are *shingled* to remove cinder and condense the mass; this process consists in hammering or squeezing for about half a minute, and the puddle ball is thereby transformed into a cylindrical bloom. The bloom is then rolled—it passes through nine or ten grooves graduated in size, and is thus rolled into a flat bar; this bar is cut into lengths, it is termed puddle bar, and its quality No. 1, or once rolled. Several bars heated and rolled into one are rolled in the rolling mill into bars of various forms of section, these cut into lengths are termed merchant bars No. 2 from having been twice rolled, and in commerce common bar iron. In the puddling furnace sometimes different salts are added to

assist in eliminating sulphur, phosphorus, and silicon; steam is used for the same purpose; powdered hæmatite and sometimes lime are added to assist the process. In the Bessemer process the cast iron is melted and poured into a suitable vessel, termed a converter, air is forced through the molten metal from the bottom of the vessel; the oxygen of the air combines with the carbon of the cast iron, and the evolution of heat consequent on this combination serves to keep the iron in fusion, and to so raise its temperature that it continues fluid during its transition from cast to malleable iron without the application of extraneous fuel; the decarbonisation having reached the required point (which is indicated by the appearance of the flame issuing from the converter, and by the time occupied, or may be tested by casting small trial ingots), the metal is poured from the converter into ingot moulds. The shingling and rolling are performed on these ingots as in the case of puddled balls, but Mr. Bessemer employs somewhat different machinery; in particular he hammers or squeezes the metal while it is enclosed, so that it cannot expand laterally, it being hammered or squeezed into dies or suages instead of between flat surfaces, by which means it is pressed more effectually into a dense homogeneous solid. To form a large object of wrought iron, a number of bars are heated and forged or rolled together; for very large forgings a vast number of bars must be piled together, and not only is there danger of the forging containing fissures, but the iron is damaged by the overheating. The Bessemer process offers great advantages in this respect, for instead of building up a large object of blooms of 70 or 80 lbs. each, a large casting containing the requisite mass of metal can be run, and this wrought to the shape desired; as no extraneous fuel is used, as in puddling, there is no fear of additional impurities being derived from this source. The process of conversion occupies about thirty minutes. Besides the above other processes are employed, but less generally, to produce the same result; many inventors have proposed to use steam to decarbonise iron: it has been tried in many ways and its use abandoned; but the Galy-Cazalat process is said to be successfully applied in France. This consists in the use of superheated steam, the steam is forced through the molten metal, it is decomposed into its constituent gases, the oxygen combines with the carbon, and the hydrogen with the sulphur of the cast iron. In Heaton's process salts are added to the melted metal, the principle of their action is the same as in other processes, they part with their oxygen, and this oxygen decarbonises the iron. Malleable iron is also made by direct reduction of the ore; this process is, however, only applicable to very rich pure ores.

305. Wrought iron is fashioned into the shapes and sizes required by forging and rolling, the two operations are essentially the same, but are performed in a different manner; the iron is heated to the welding temperature and then fashioned, in the one process by the hammer, in the other by passing it between rollers either simply cylindrical or having grooved surfaces, a number of pieces being piled together, heated and forged or rolled to form the required mass. Repeated heating and rolling or forging, up to a certain number of repetitions, improves the quality of the material, increasing its toughness; it is therefore a common practice to heat and work the iron several times in the rolling mill to improve its quality; such iron is distinguished as *best, best best*, &c., each "best" signifying an additional working and a higher price. Cast unhammered ingots of Bessemer iron have a mean tenacity of 18·412 tons, this tenacity is increased to 30·5 tons by rolling into boiler plate, the ratio between these is 23 : 38; the improvement due to this cause is however limited. In a series of experiments made by Mr. Clay the improvement continued to the sixth working; at the commencement the puddled bar had a tenacity of 43,904 lbs., after the sixth working it had increased to 61,824 lbs., and after the twelfth working the tenacity was the same as at the commencement. It follows from the above that iron required to be much worked in fashioning should not be selected from those kinds which have already been much worked, and iron of good quality should be heated as few times as is consistent with working it at a proper temperature, such iron having already (as a rule) been improved to its maximum. In large forgings the tenacity is reduced by the overheating, and by the size of the mass operated upon being such that the effect of the working does not extend through the whole mass. The tenacity is reduced by these causes one-fourth, sometimes more, below that of the bar iron employed. Bars of small section are as a rule stronger than those of large for the above reason. If iron be hammered too cold it is rendered brittle, this should therefore be carefully avoided. Large masses rolled or hammered are very slightly inferior in strength in the centre, the effect of the working being less there than at the exterior; therefore as a general rule it is better to forge down a bar than turn it down, and when the bar has to be much reduced at any part, the work will be stronger if it be reduced partly by forging and partly by turning, than if wholly reduced by turning. Although hammering hardens the metal superficially, the value of the hardened skin is trifling compared with that of cast iron. Mr. Kirkaldy states the prevailing opinion of a rough bar being

stronger than a turned one is erroneous, but this must depend on the size of the specimen from which the bar is turned; for Mr. Kirkaldy admits the additional hardness of the skin of the rough bar, and it follows that if this skin be turned off the turned bar will be weaker in proportion to its area than the rough bar; this conclusion is in accordance with the admitted fact that hammering hardens the metal superficially, and is confirmed by the results of Professor Rankine's experiments on forged and turned journals. Iron rolled cold has its density decreased; its tenacity is increased, as in the case of hammer hardening, by it being rendered hard and brittle; wire-drawing produces the same effects. Rolled bars are slightly hardened by forging down. Repeated working renders iron more homogeneous and constant in quality; there is therefore less difference in strength between bars of high than between bars of low quality, and in low qualities there is greater difference between large and small bars. Iron is injured by heating to the welding heat, unless it be rolled or hammered while heated; if quenched in water when hot it is rendered more elastic, tenacious, and brittle, but the degree to which this effect is produced is influenced by the quality of the iron, particularly as regards the proportion of contained carbon. Both in rolling and forging the manner of piling the bars together to form the mass influences the value of the result; thus a forging built up of small bars is more likely to be sound than if a very few large bars be employed, for the liability to extensive fissures consequent on imperfect welding is less in the former case. If the bars be piled all in the same direction, the strength of the forging bar or plate will be greater in the direction the bars are piled than at right angles to this direction; thus when strength in one direction is required the bars are piled in this direction; when the strength is required to be as nearly as possible equal in all directions, as in plates, the bars are placed together in layers, those in each layer being placed at right angles to those in the layers above and below it. A fibrous texture is produced by rolling, the fibre is in the direction of the rolling, and the tenacity is usually greater in the direction of this fibre than at right angles to this direction; but in plates, if the bars are properly piled this difference is very small; although M. Navier observed a difference of 10 per cent., Sir W. Fairbairn found the strength in the two directions almost equal. In large forgings the fibre is in the direction the bars are piled, and this difference is very marked, amounting to upwards of 6 per cent.; in this case it is seldom possible to arrange the bars as is done in the case of piling for plate rolling. The ductility is greater in the direction of the

fibre, and the mechanical properties appear to be more constant in this direction than in a direction at right angles to it. The product is more certain in its properties, and more equal in strength in different directions when made from the ingot, as when Bessemer metal is used, than when made from small bars or scrap iron, and the risk of overheating is diminished, if not quite removed. Small-sized bars are more tenacious than plates; this difference is as much as 14 per cent. when the bars are under about three inches; it may be due to the fibre being produced by the piling and rolling being in the same direction. Hot rolling decreases the density of some qualities and increases that of others.

306. Common plate iron is rolled from the bloom, and is very inferior in tenacity to the superior plate, frequently one-third less. The best plate is rolled from No. 2 iron, the bars being piled an equal number in the directions of the width and length; the plate is extended by rolling only in one direction, that of its motion, hence to increase the width it must be rolled sideways. Bars are rolled of different sections by means of suitably shaped grooves on the rollers, but a limit is set to the complexity of the form of section, for when the iron is much distorted its strength is impaired. Complex sections are difficult to roll, because the strain is different at different parts of the section during the rolling; this tends to tear one part of the bar from the other, and thus injures the iron. There is also risk of unsoundness when angle bars and plates are rolled exceeding an inch in thickness; hence complex forms and thick masses are preferably built than rolled entire. Bars or strips are not as a rule rolled wider than 9 inches. Plates less than $\frac{3}{10}''$ in thickness are commonly termed sheet iron. When plates are required to be wider than 4 feet, longer than 15 feet, or heavier than 4 cwts., an addition is made to the price; but they are rolled up to 7 feet wide, 30 feet long, and 60 feet in area.

307. Assuming the iron to weigh 480 lbs. per cubic foot (a fair average for rolled iron), a plate 1 inch thick weighs 40 lbs. per superficial foot; the weight being proportional to the thickness, the weight per foot for any other thickness expressed in inches may be readily ascertained—*e.g.*, plate $\frac{1}{8}''$ thick weighs 5 lbs. per foot, &c. The weight of bars per yard run may also be readily ascertained, for $1'' \times 1'' \times 1$ yard $= 36$ cubic inches $= 10$ lbs.; therefore ten times the area of transverse section in square inches, is equal to the weight per yard run in pounds—the same rule manifestly applies to wires.

308. Welding is easier performed on soft iron containing very little carbon than on the hard steely qualities. Mr. Kirkaldy

found the tenacity of joints in bars cut and welded varied between almost equality with the uncut bar, and one-third less. Professor Rankine states, in an experiment on the bursting of a cylindrical plate-iron welded retort, the tenacity of the weld was estimated at probably three-fifths of that of the plate. In some experiments described by Mr. Anderson, the object of which was to compare welded joints in iron of different qualities, and to compare such joints made in different ways, the results were as follows:—In soft iron of the best quality with scarfed joint the strength of the weld was equal to that of the bar; with harder qualities the strength of the weld was in every case less than that of the bar; and in the worst example, the iron being very hard and steely, the weld had less than one-fifth the strength of the bar. Butt welds were found weaker than the scarfed welds. In all cases the surfaces of the joint were rounded in order that oxide and other superficial impurities might escape. Mr. Anderson attributes the weakness of the welds in the harder qualities to the steely property or the presence of carbon. It should be remarked, that steel containing less than 1·5 per cent. of carbon can be and is commonly welded, both to steel and iron, without other precautions than avoidance of such exposure to a high temperature as would burn the steel, and the union in these cases appears perfect; hence, with such precautions, it would appear hard iron can be well welded, but the welding, as in the case of steel, is difficult and uncertain, the metal being so readily burned. Only workmen used to the process succeed in welding steel. Plate welding has been proposed instead of riveting; but although successful so far as the strength of the joint is concerned, practical difficulties have prevented its general adoption —the welded joint can be made nearly if not quite as strong as the plate. Plate welding is, however, used in preference to riveting for some few purposes, and no doubt with great advantage. In welding and all operations in which the iron is heated to welding heat, the fuel used should be as free from sulphur as practicable, and not of a kind to form clinker on the iron; for small occasional operations, such as mending or repairing tools, dense charcoal is probably the best fuel.

309. Sir W. Fairbairn found the tenacity of boiler-plate was not appreciably diminished at a temperature of 395° F., but at a dull red heat it was diminished by about one-fourth. The tenacity of good rivet iron (the toughest and most ductile quality) increased with elevation of temperature to about 320° F., at which point it was about one-third greater than at ordinary temperatures; beyond this point it decreased, and at a red heat had fallen to rather more than half its original value.

Difference of opinion exists concerning the effect of subjection to low temperatures, it is generally supposed that iron is rendered more brittle. Mr. Kirkaldy found the ultimate tenacity reduced at 32° F., but the difference was less when the load was applied gradually than when applied suddenly—*i.e.*, the iron was rendered brittle. At the lowest natural temperatures of temperate climates this effect is too minute for practical consideration.

310. The co-efficient of expansion of malleable iron is greater than that of cast iron, it varies in different qualities; the linear expansion between 32° and 212° is variously stated between $\frac{1}{846}$ (Dulong and Petit) and $\frac{1}{644}$ (Troughton); in the latter case thread from the drawplate was used, and the result favours the assumption that the co-efficient for thin wire is higher than for bars and plates. Smeaton's observations gave $\frac{1}{795}$, and those of Lavoisier and Laplace $\frac{1}{819}$; the iron in the latter case is stated to have been "soft." In practice the value commonly assumed is $\frac{1}{833} = \cdot 0012$, or $\cdot 0000067$ for one degree; this value is somewhat below the truth.

311. Mercury does not act on iron directly, hence it is kept in iron vessels. There is great affinity between iron and gold; for small delicate work gold is recommended as better than copper for soldering iron. Tin and iron readily form an alloy, and melted tin is a powerful solvent of iron, one part of tin being sufficient to cause the fusion of five parts of iron at a much lower temperature than would be sufficient without the tin. The possibility of alloying iron and zinc has been disputed; MM. Dumas, Berthier, Karsten, and others contend that such alloy is possible, whereas M. Thenard and others deny this possibility; the metals are found naturally alloyed, and iron is a common impurity in zinc. The evidence appears in favour of the possibility, but no doubt the affinity between the metals is very slight indeed. The alloys of iron are not used in the arts, but iron alloyed superficially with tin is very common, as is also iron covered with zinc; from the difference between the affinities of these metals for iron, it appears probable zinc should impair the strength of iron less than tin, zinc-covered (galvanised) iron should be preferred therefore where strength is desired. Mr. Kirkaldy found no sensible effect was produced by tinning or galvanising on the strength of iron plates $\frac{3}{16}''$ to $\frac{5}{8}''$ thick, very thin plates are probably weakened by tinning, and in a less degree by galvanising. Tinning is performed by immersing the plates in melted tin after cleaning them with very weak solution of sulphuric and muriatic acids, heating them to redness, and scouring them with sand. Galvanising is performed as follows: —the iron is first pickled in a solution of sulphuric acid, it

is then dipped into a solution of chloride of zinc, dried, and finally placed in a bath of melted zinc covered with fused chloride. The articles should remain immersed until the temperature of the bath is the same as before their immersion, they should then be removed, and subsequently well washed in a solution of soda to prevent corrosion by adherent chloride of zinc. Sometimes a simple bath of solution of muriatic acid is used to clean the iron, but the result is inferior. An excellent mode of galvanising is to immerse the clean iron in a solution of a compound of oxide of zinc and potash, and deposit the zinc on the iron in the usual way by means of a battery. It should be remarked that metallic coatings preserve the iron only so long as they are continuous, when they become discontinuous they hasten oxidation; hence galvanised wire should be well covered, and in making joints in galvanised wire care should be taken to re-cover with tin any part denuded of zinc.

312. The softer and more fibrous qualities are more readily corroded than those harder and more crystalline. Vibration has the effect of reducing the liability to corrosion, therefore in store iron is more liable to corrode than when in use. When corrosion has commenced at any part it spreads rapidly, probably by reason of a galvanic action between the rust and iron. Before painting iron the rust should be scraped off, excepting sufficient to leave a rough surface for the paint. Iron cells and other closed structures rust less rapidly in the interior if they be closed to prevent the contained air being frequently changed.

313. An extensive series of experiments was made by Sir W. Fairbairn, to compare the stiffness or pliability of wrought and cast iron under various conditions of load; the results of these experiments were as follows:—For tensile forces not exceeding in intensity 7·5 tons per square inch the mean elongation of cast iron is about two and a quarter times that of wrought iron, the ultimate extension of the cast iron is about three times that of the wrought iron, and within this limit of load the set of the cast iron is considerably greater than that of wrought iron. Within the limit of 6 tons tensile load for cast iron and 13·5 tons for wrought iron, to produce equal elongations in cast iron and wrought iron, the loads must be as 1 : 2·25. When the intensities of the loads are 5·5 tons for cast iron and 12·5 tons for wrought iron per square inch, the sets and strains are respectively equal to each other; the ultimate strain of wrought iron per ton per square inch is about eight times that of cast iron, and the relative ultimate strains of wrought and cast iron are as 26 : 1. In other experiments made by Mr. Lloyd with wrought iron having the exceptionally high average tenacity of 32 tons per

square inch, the relative ultimate strains were as 130 : 1. When the intensities of the loads exceed 12·5 tons for wrought iron, and 5·5 tons for cast iron, the set of wrought iron is the greater; and for loads exceeding in intensity 15 tons per square inch, the set of wrought iron greatly exceeds the ultimate set of cast iron. In Sir W. Fairbairn's experiments, when the intensity of the load was 15 tons per square inch the set was ·5 of the strain, when the intensity was raised to 20 tons per square inch the set was ·917 of the strain. Mr. Kirkaldy found the relation between the strain and stress varied extremely in different qualities of wrought iron, and to a considerable extent in specimens of the same brand. The above results have great practical value, demonstrating the conditions which must be fulfilled when cast iron and wrought are combined to mutually assist each other in resisting a load. If cast iron and wrought iron be combined in a beam, the cast iron resisting compression and the wrought iron tension, the two materials do not act together, hence such beams are not used. If a cable tank of cast iron is to be strengthened by hoops of wrought iron (a common mode of making water tanks), if the wrought iron hoop were put on cold, for loads less in intensity than 7·5 tons per square inch the intensity of the load on the wrought iron would be only four-ninths that on the cast iron; because, below this limit the load, on cast iron and wrought to produce equal strains must be as 1 to 2·25, hence the wrought iron would be less efficient than an equal mass of cast iron. If however, the wrought-iron hoops be shrunk on by being placed on hot, that by cooling they put a compressive load on the cast iron, then they are more useful than an equal quantity of cast iron would be, and lightness as compared with a tank of cast iron only is practicable. Suppose the wrought iron to have a tension of 3 tons per square inch when the strain on the cast iron is that due to its working load, say 1·5 ton per square inch, the strain on the wrought iron will correspond to a load $= 1{\cdot}5 \times 2{\cdot}25 = 3{\cdot}375$; this together with the original load of 3 tons would make the intensity of the load on the wrought iron 6·375 tons; as the working load on wrought iron is about 5 tons this is too much, the best tension to put on the hoops is between 2 and 3 tons. The set of cast iron under the action of a load limited as supposed is much greater than that of wrought iron, but this can be allowed for in putting tension on the hoop.

314. Some kinds of iron are *red short*, others *cold short*, the cause of these peculiarities are stated above. Red-short iron is difficult to work as it is brittle when heated, and this may prove a source of insecurity in some cases, but in general cold shortness is a more serious defect, as its consequences are unavoidable.

315. The average strength of bars and plates of wrought iron as compared with cast iron is about as follows:—the tenacity of wrought iron is about three times that of cast iron, and the resistance of the former to crushing is about one-third that of the latter; but both materials differ very widely, and the above statement is a general one not given as applicable to particular cases.

316. The tenacity and resistance to crushing of wrought iron cannot be compared in general terms with any pretence to accuracy, as there is great difficulty in determining the point at which the softer qualities begin to yield to compression; in bars and plates on the average the resistance to compression is roughly somewhat less than two-thirds the tenacity. In hard qualities the tenacity and the resistance to crushing are both high, and in soft qualities both are low; annealing or other process which reduces the hardness and brittleness also reduces the tenacity, and *vice versâ*. A high tenacity is not alone a test of good quality, for it may be accompanied by brittleness; the best qualities are not the most tenacious, they have a high ductility with the maximum tenacity consistent therewith, compared with some inferior qualities the tenacity may be low. Hard brittle iron is unsuited to resist shocks, difficult to weld, and readily weakened by punching rivet holes, hammering, &c., therefore although its tenacity is higher, for most purposes it is less reliable than softer qualities. There is much inferior iron in the market which has a high tenacity and low ductility; telegraph wire has usually a low tenacity compared with ordinary hard wire although usually dense and fine in quality, the weakness being due to extreme softness. Mr. Kirkaldy was led by results of his experiments to consider the contraction of area at the section of rupture an essential element in estimating the quality of iron, from experiment on its ultimate tenacity; and that this area is an important element indicating the degree of ductility is generally admitted, but its precise value or significance is not perfectly known, as it is not determined to what extent it is influenced by other conditions than ductility of the iron, such as the shape of the specimen, &c.

317. Some authorities consider iron is altered in texture and rendered brittle by being subjected to vibration and repeated shocks, although the strain may not exceed the proof strain. It is known that repeated applications of a load exceeding the proof load ultimately produce fracture, and it is contended therefore that for shocks and vibration to cause brittleness the strain must exceed the proof strain. The evidence on which it is concluded that structural change takes place is somewhat inconclusive, not

being founded on accurate experiment, but in a great measure on —*firstly*, observation of the appearances presented by the fractured surfaces of axles, shafts, chains, and similar objects; *secondly*, the fact that such objects fail after being in use for some years, the only admissible explanation of the failure being loss of strength or deterioration of the material; and, *thirdly*, the fact that annealing is found to prevent failure, the explanation of which is the production of a molecular change, an explanation in accordance with the results of conclusive experiments, annealing having been found to restore the strength of over-strained beams, plates weakened by punching, &c. Mr. Kirkaldy found iron fractured suddenly invariably presented a crystalline appearance, when fractured slowly its fracture was invariably fibrous. He found the appearance of the fractured surfaces might be altered by the shape of the specimen, and by its relative hardness, accordingly as these conditions rendered the iron more or less liable to fail suddenly without stretching. In the fibrous fractures the threads are drawn out and clearly exhibited, the section of fracture is irregular; in the crystalline fracture the fibres are broken across, they are viewed endwise, the section of fracture is always at right angles to the axis of the bar, and the contraction of transverse area at the section of fracture is less than when the load is applied gradually. Professor Rankine's observations and the results of his experiments on journals of railway carriage axles are at variance with Mr. Kirkaldy's experiments; the crystalline fracture was not invariably presented by axles broken by the hammer, some exhibited the fibrous and others the crystalline appearance. From the above it may be concluded—1. Iron should not be unnecessarily subjected to sharp shocks and violent vibration; 2. when such is unavoidable, as in crane chains for example, the iron should be periodically annealed to reduce the risk of failure; and 3. a crystalline fracture does not necessarily indicate absence of fibre, on the contrary, it is consistent with the fibrous texture, and may be due to the manner in which fracture was caused.

318. The tenacity of malleable iron (not wire-drawn) varies between about 15 and nearly 33 tons per square inch; both these extremes are exceptional. Twenty-five tons is commonly assumed as the average tenacity in practical calculations, but this is too high. Below 20 tons the iron is regarded as inferior, but, as already explained, the ductility of the metal must be taken into account, for the weakness may be due to insufficient working, bad metal, or merely to extreme softness; on the other hand a high tenacity may be accompanied by brittleness, and iron exceptionally tenacious is generally hard and brittle. After comparing the principal authorities on the subject, the following

conclusions have been arrived at. Exceptionally bad qualities are excluded, and the strength is expressed in tons on the square inch :—Bars vary in tenacity between 18·4 tons and 29 tons, the average of the several qualities is about 24 tons; Bessemer iron ingot 18·4 tons, worked 32·4 tons. Plates appear less variable, but their average tenacity is lower, it varies between 19 and 27·3 tons, the average of many descriptions is 23·25 tons, or between 3 per cent. and 4 per cent. less than the average of bars; in practice the average is lower, being between 22 and 23 tons. Bars are sometimes as much as 16 per cent. stronger than plates; in small sections they are about 14 per cent. stronger as a rule. In Bessemer iron the difference is less, boiler-plate has a tenacity of 30·5 tons, the difference between bars and plates is 6 per cent. The above figures relate to longitudinal tenacity. Plates are as a rule weaker loaded transversely, this difference is in general about 10 per cent., the average found by M. Navier; it is occasionally much less, it is probably less in Bessemer iron, but the author has not seen any records of experiments. The tenacity of specimens cut from crank-shafts and other large forgings is greater lengthwise of forging than crosswise; the differences in Mr. Kirkaldy's experiments were 6·25 and 16 per cent. The averages obtained by several earlier authorities are higher than those given above; the average of Mr. Telford's experiments was 29 tons, but the ultimate elongation shews the iron to have been hard; Mr. Brunel, in three sets of experiments, found the averages to be 30·4, 32·3, and 30·8 tons respectively; Mr. Rennie and Captain Brown both found the average near 25 tons. Forged iron in large masses varies in tenacity between about 15 and 21 tons per square inch, the average is probably somewhat higher than the mean of these numbers. Rivet iron has the maximum tenacity consistent with a high degree of ductility; its tenacity varies between about 26·5 and 27 tons. Bolts, thin bars, and high quality hoop iron, average about 29 tons. The tenacity of cable iron for chain making received from several factories, was between 20 and 24 tons (Prud' homme); a soft iron easily welded is used for this purpose; the best English chains are made of iron of a quality similar to that of rivet iron. The strength of oval linked chain of this iron is about 15·25 tons, and of cable chains 20·3 tons per square inch of section, the ratio between the numbers being 7 : 9 nearly.

319. The process of wire-drawing increases tenacity and hardness; but annealing restores the softness and reduces the tenacity. The relative tenacity of thin wire is, as a rule, greater than that of thick unless it be annealed. The following are some values obtained by or deduced from experiments, the wire not having

Strength of Telegraph Wire in Tons per Square Inch of Section.

B.W.G.	Diameter.	No. 1.	No. 2.		No. 3.		Decrease per Cent. due to Annealing.	
	Inches.	Soft.	Hard.	Soft	Hard.	Soft.	No. 2.	No. 3.
0000	·454		35·80	24·80			31	
00	·363				37·23	26·00		31
1	·300		34·71	24·39	37·72	25·15	30	28
2	·280				34·92	24·48		30
3	·260				33·69	21·71		36
4	·240				33·73	24·80		25·5
*4	·236	25·62						
5	·220		34·09	25·26	34·67	25·85	26	28
*6	·197	25·50						
6	·203		34·48	24·82			28	
6	·200				36·00	25·92		28
7	·185				37·00	25·10		32
*7	·177	25·87						
8	·170				33·97	23·29		31·5
9	·155				34·34	21·75		36·6
10	·140				33·48	22·88		32
11	·125				29·28	23·205		21
11	·120		35·12	25·21			30	
*11	·118	26·00						
12	·110				31·70	22·77		28
13	·095		37·73	25·15	40·24	25·15	33	37
14	·085				39·94	27·41		31
14	·083		39·15	26·79			31·6	
15	·075				41·60	30·44		27
15	·072		38·37	29·05			24	
16	·065		40·34	24·20	47·35	27·00	40	43
*17	·059	26·16						
18	·050				44·64	25·67		45
18	·049	26·04	37·87	23·67			37·5	
19	·045				41·85	23·715		43·6
*20	·039	26·158						
20	·040				37·77	22·36		41
21	·035		37·94	22·32	37·94	22·32	41	41
22	·030				41·45	25·50		38·5
22	·028		36·60	21·96			40	
Averages		25·90	36·85	24·80	37·205	24·65	33	33

* In these wires the sizes only approximate to those of the numbers placed against their diameters; the other sizes and diameters are given by different authorities as the correct Birmingham wire gauge, but it should be remarked the authorities differ.

been annealed after drawing; the strength is stated in tons per square inch:—·1″ diameter, 36 tons (Barlow); ·2″ to ·05″ diameter, 35 to 43 tons (Telford); wire for Niagara bridge, 45 to 46 tons; for Freiburg bridge, 50 tons; ·126″ to ·122″ diameter, 49·1 to 52·5 tons (Prud'homme); 31·75 to 57·15 tons (Morin); 31·25 to 44·64 tons (Rankine); average 41·7 tons (Dufour); 47 tons (Vicat). The preceding table has been calculated from the circulars of three separate firms which manufacture large quantities of telegraph wire; the numbers represent the contract ultimate tenacity in tons per square inch of section, the numbers heading the columns distinguish the several manufacturers.

The iron used for drawing into telegraph wire is of good quality, commonly "best best," as a high degree of ductility is almost invariably specified; the tensile strength shewn in the table is lower than that stated for iron wire generally by some of the authors quoted, by reason of the softness of the iron. Charcoal iron was formerly more commonly used than at present for wire, but it is more expensive than "best best" ordinary iron, and the latter is in general use. The average tenacity of hard wire is about 37 tons; that of soft wire between 24 and 25 tons in Nos. 2 and 3, and nearly 26 tons in No. 1. The quality of No. 1 is very constant; in Nos. 2 and 3 the strength varies, No. 3 being the more variable; constancy is probably an evidence of care in manufacture, particularly in soft wire. Hard wires less than ·1″ in diameter are somewhat stronger than larger sizes, the averages being No. 2, 38·3 tons, and No. 3, 41·4 tons. Soft wires vary very little in strength, the averages are 24·75 and 26 tons for the small sizes, the loss of strength by annealing these sizes being 35 per cent. and 38·5 per cent. respectively. The effect of wire-drawing is to harden the iron and raise its tenacity from rather more than 24 tons to an average of about 37 tons per square inch, or nearly 50 per cent.; for sizes larger than ·1″ diameter the increase is rather less, in smaller wires the strength is raised to about 40 tons. The effect of annealing is to reduce the tenacity of the wire to that of the original bar. There are variations in strength probably due to the mode of manufacture, but the maximum tenacity appears to be developed between about 14 and 16 B. W. G. in Nos. 2 and 3; it is highly probable repeated working renders the iron weak after improving it up to a maximum. Hard wire differs considerably in tenacity, the extremes being, No. 2, 34·09 and 40·34 tons, No. 3, 29·28 and 47·35 tons, the differences being 5·25 and 18·07 tons respectively; the differences for soft wire are ·66 ton, 7·09, and 8·73 tons respectively; probably with greater care in annealing Nos. 2 and 3 would be rendered more constant, for omitting two wires in one and three in the

other the differences are reduced 50 per cent. For hard wire no average tenacity can be assumed, nor can it be assumed in practice that a small size will be certainly proportionately stronger than a larger; but a tenacity of 24 tons per square inch may be safely assumed for good quality soft wire, and this tenacity ought to be maintained. A high degree of ductility is a necessity in telegraph wire, but there appears a needless sacrifice of strength in favour of ductility when the smaller sizes are used extremely soft. Not only a minimum ductility but a minimum tenacity also should be specified, but care should be taken not to specify inconsistent conditions. Many engineers insist on extreme softness, others do not insist on the thinner wires being thoroughly annealed. It is evident from the above table that stranded wire if soft is no stronger than solid wire of the same sectional area, but it is more costly and exposes a greater surface to corrosion, hence the single wire is safer; but stranded wire if hard or only partially annealed is stronger than similar single wire equal to it in sectional area. It should be remarked, that the above observations refer only to wire of the descriptions referred to in the tables—viz., of "best best" iron.

320. The ultimate extension of malleable iron depends in a great measure on the relative hardness of the specimen; a very soft specimen may elongate as much as 30 per cent., and a very hard specimen may elongate only 1 per cent.; bars not exceptionally brittle elongate from 13 to 30 per cent. before breaking; plates are less variable than bars; excluding bad qualities, the longitudinal extension varies between 4 and 17 per cent., the transverse extension is from 10 to 50 per cent. less than the longitudinal. In some of the highest quality plate-iron the longitudinal extension varies between 5 and 7 per cent. The ultimate elongation of wire varies between the most extreme limits stated above; the hardest wire snaps without sensibly elongating, the softest will stretch 30 per cent. Annealed telegraph wire is usually specified to stretch at least 16 to 20 per cent.; 25 per cent. is common in the soft wire commonly used.

321. The resistance offered by malleable iron to crushing is on an average about 17 tons per square inch; in practice it may vary about 1 ton more or less from the average. The softer qualities flatten out, and their strength cannot be accurately determined. M. Rondelet found an inch cube bore 31 tons; Mr. Hodgkinson found an intensity of 9 to 10 tons per square inch produced a slight set, and 27 to 30 tons flattened the specimens through one-sixteenth of their length. The following results of experiments made at Woolwich are given by Mr. Anderson:—

Specimens cut from bars ·75″ to 2·5″ square, 50 tons per square inch produced a set of about ·25″; a set of ·003″ was produced by 13·4 tons in one specimen, and between 14 and 15 tons per square inch in two others; three other specimens of iron required between 11 and 12 tons, and one 14·2 tons per square inch—the specimens were short cylinders ·533″ diameter and 1″ long. The resistance of iron in the interior of large forgings was found to be less than the figures stated above; 11·5 tons per square inch was the average intensity of load required to compress the iron ·003″. Sir W. Fairbairn found the ultimate load of a hollow square pillar 8′ long 1′ 6″ square, and made of plate ·5″ thick, to be equal to 13·6 tons per square inch; the tube failed by buckling. Malleable iron is seldom subjected to compression in such forms as to render the determination of its ultimate resistance to crushing of importance; as a rule it fails by buckling.

322. The transverse strength of malleable iron differs as widely as its tenacity. Mr. Kirkaldy found the constant (strength of a bar 1 inch square supported on supports 1 foot apart and loaded in the centre) for Swedish bar iron 3473 lbs.; but plates are much weaker, and for ordinary plate beams the constant is only about two-thirds this value. The resistance of wrought iron to shearing is somewhat less than its tenacity; in good rivet iron it averages about 21 tons per square inch. The torsional strength of wrought iron is commonly assumed to be 1000 foot-pounds per square inch; with the other mechanical properties of the material it varies very widely, and in practice is between 700 and 1000 foot-pounds per square inch.

323. A riveted joint has a less tenacity than the plates or bars connected, by reason of the reduction of sectional area by the rivet holes. The joint sectional area of the rivets should evidently be equal to the sectional area of the plate or bar after punching the holes; in practice the rivets are frequently slightly larger than this rule prescribes. The tenacity of single riveted joints is about 13 tons, and of double riveted joints (the rivets placed zig-zag) 16 tons per square inch; or the tenacity of the plate being 100, that of a single riveted joint is 56, and of a double riveted joint 70. When the rivets are arranged in rows in the direction of the tension (chain riveting), the plate is not necessarily so much weakened, and the joint may more nearly approximate to the plate in tenacity; such joints may have a tenacity of 17·75 to nearly 21 tons per square inch.

324. The resistance of iron to a bursting force is stated by one author to be 70,000 per square inch—*i.e.*, its extreme tenacity; it cannot exceed the tenacity, and if the vessel burst be thick compared with its lateral dimensions it may be much less. The

intensity of pressure in pounds per square inch required to burst a thin hollow cylinder is obtained by multiplying the tenacity of the material in pounds per square inch by the thickness of the cylinder, and dividing the product by the radius; the ratio of thickness to radius to resist a given pressure may be obtained from the same formula: the ultimate stress on the material is evidently equal to its tenacity or the tenacity of its joints. This formula applies to tanks for cables, boilers, and all similar structures in which the thickness is small compared with the diameter. The resistance of a spherical shell is twice that of a cylinder equal to it in radius and thickness. The intensity of external pressure necessary to cause collapse of a thin hollow cylinder with butt joints was found by Sir W. Fairbairn to be inversely as the length, inversely as the diameter, and directly as the 2·19th power of the thickness; slight departure from the circular section seriously impaired the strength, and when rings of angle or hoop iron were riveted round the tubes at intervals, their strength was raised to that of tubes equal in length to the distances between rings. The thickness t and diameter d being expressed in inches, and the length or distance between two rings l being expressed in feet, the ultimate resistance R is approximately $R = 806{,}000 \frac{t^2}{ld}$.

325. The resistance of plates to bending or buckling under compression was found by Mr. Hodgkinson to vary nearly as the cube of the thickness, their other dimensions being constant. In Mr. Mallet's buckled plates great strength is obtained by making the plate convex in the centre, and surrounding it by a flat rim or fillet, which suffers extension when under the action of a load the convexity in the centre is compressed; they usually fail by being pressed flat at the centre. The working load varies with the square of the thickness within the limits of ·048″ and ·375″. A plate 3 feet square, ·25 inch thick, and having a convexity of 1·75 inch, bears 4·5 tons, and 3 tons, for steady and moving working loads respectively.

326. The proof strength of wrought iron is about one-third of its ultimate strength; the factor of safety for a dead load is 3 to 4, for a live load 6; 4 is commonly employed in telegraph structures, but as applied to the wire, in some cases, it is somewhat too low, because the load is not entirely a dead load, and the load on the wire is not usually measured. As the wire is soft, when subjected to vibration and tension it stretches, and thus if the tension be too great it is reduced by elongation of the wire, but this should be avoided, particularly in thin wires, and for hard wires a higher factor should generally be used. Wrought

iron may be loaded to half its ultimate tenacity for purposes of proof, the load being only applied once for a short interval, and without vibration or impact, although repeated application of the same load would ultimately cause fracture. Beams are commonly tested to half their ultimate strength, the same precautions being observed. In testing ironwork containing joints, by its deflection, allowance must be made for the yielding of the joints on the first trial; in plate beams the trial deflection is increased 50 per cent. by this yielding, and only after this has taken place is the deflection the same as that for a solid rod. The factor of safety commonly assumed for wire ropes is 7 for a live load; for stays and ties to telegraph posts 4 is sufficiently high; for stranded wire used for overhead lines in towns a somewhat higher factor should be employed. Chains are proved to about $\frac{10}{19}$ of their ultimate load; cables stretch about 3·3 per cent., and short-linked chains 4·4 per cent. under proof. There is much difference of opinion on the intensity of the working load actually admissible in practice—a common rule is to allow 5 tons per square inch for tensile, and 4 tons for compressive loads respectively; by some authorities these intensities are only permitted in iron of good—*i.e.*, above average quality. One authority allows 4 tons in large, and 3 tons in small sections for compression, 5 tons tension for ordinary plate iron, 5 tons for ordinary bar, and 6 tons for extra good bar per square inch. Another authority allows 7 tons tension, and 5·5 tons compression, if the load is all dead; but when the load is mixed a higher maximum intensity is admitted for the dead load the greater its ratio to the live load; when the load is practically all live 3·5 tons and 2·75 tons tension and compression respectively are the limits. The Board of Trade rule for railway bridges permits the following factors of safety:—All dead load 3, with vibration 4, with shocks 6; and allows in the first case 5 tons for both compression and tension. The French rule limits the intensity of the load to 3·81 tons per square inch. The most rational mode is to estimate the strength of the iron as nearly as practicable, and use a factor of safety; 4 in ordinary cases, as for poles, and rather more for wire, raising this to 6 when severe shocks are to be anticipated, and increasing it to 10 or even higher in the case of chains, shafts, and similar bodies liable to the shocks due to a suddenly arrested falling weight, or the sudden stoppage of machinery; even in the latter cases the mechanical value of the greatest possible shock can be estimated, and the factor of safety should depend on calculation (*vide* Paragraph 57).

327. The deflection of wrought iron under a transverse load

must be kept below $\frac{1}{500}$ of the span or the material receives a permanent set; it is usually limited in plate girders to $\frac{1}{1000}$ of the span for the working load, the depth of beam varying between about $\frac{1}{10}$ and $\frac{1}{15}$ of the span, the average is about $\frac{1}{14}$, but $\frac{1}{12}$ is considered by some authorities the most economical as regards material. The above data, together with those given in Chapter II. section 6, are applicable to telegraph poles considered as cantilevers, and the formulæ given in Paragraph 144 are applicable. In telegraph poles the relation of depth to length stated above as adhered to in designing beams, must be regarded as a limit, the ratio used for beams not being adhered to; but in respect to deflection and set the case of a telegraph pole does not differ from that of a beam; if in any case the deflection exceed the stated fraction of the span a set is the consequence. Manufacturers of poles usually state the weights of the poles, and their ultimate loads as cantilevers; but the deflection with the proof load should be ascertained in order that the best form may be decided upon in any particular case. Strength cannot be considered apart from stiffness, because a pole having a relatively high ultimate strength may have a relatively low proof strength —*i. e.*, it may be badly bent by a smaller load than would sensibly distort a pole of another pattern, notwithstanding that the ultimate load of the second pole be lower than that of the first. If the strength be alone considered, the greatest strength is obtained with a given mass of matter when the thickness of the tube is $\frac{3}{20}$ of the diameter, the transverse strength of the tube is then twice that of a solid cylinder containing the same quantity of matter; if the stiffness be so fixed that under the proof load the deflection shall be restricted below that which would cause a sensible set, then the depth of the tube must bear that same ratio to the span as is adopted for wrought-iron beams. Some engineers adhere as nearly as possible to the proportions for beams as in Morton's oval pole and the poles of Messrs. Hamilton & Co. (both of which patterns have been patented); in the latter the proportion of depth (diameter) to height in the simple poles varies between ·0317 for the weakest and ·053 in the strongest, the wrought-iron portion only being included; the smallest fraction common in girders is ·06. An example in which the strongest form for a given mass is approached as nearly as practicable is the Siemens pattern, the pole consists of a cast-iron basement segment standing 4′ 4″ clear, and of a welded iron tube making the total height 17 feet clear, the diameter at the base is 4 inches, the ratio is therefore ·0191, in the case of the wrought iron alone it is ·046. The ratios of thickness to diameter are in the Hamilton pole approximately

·018 and ·012, for the weakest and strongest poles respectively; in the Siemens pole, it is for the example given above, for the cast segment ·0625, and for the wrought iron ·0716, and the inventor claims the proportion is about that which gives the maximum *strength* for a given mass of material. The following appear the principal reasons for departing from the proportions adopted for beams:—Telegraph posts are required to be lighter in proportion to their length than beams, as the load they are required to resist is comparatively very light, the weight of the pole sometimes reaching one-third of its load; hence such provision cannot be made to ensure stiffness without making the metal too thin for strength; whereas a beam has to bear its transverse load either continuously or frequently repeated, the transverse load on a telegraph post is the exception and not the rule, stays or struts being generally used when the load exceeds a very light one. The production of a set, unless considerable, being due to exceptional circumstances, causes no inconvenience, it is therefore cheaper to allow the set to be produced in the exceptional cases than to prevent it by providing against it in every pole; a pole accidentally bent is unsightly, but the cause which operated to produce the set having ceased to operate or recur, the stability of the structure is not endangered as the existence of a bridge would be if passing loads produced such a set on its girders. From the above it is evident, ordinary iron poles are unsuited to bear any but light transverse loads compared with their section, by reason of their inadequate stiffness; therefore, the practice of dispensing with lateral support on curves and placing the poles nearer each other can only be adopted in any case after it has been ascertained that the particular poles are sufficiently *stiff* for the purpose. Adequate stiffness not being supplied by the pole alone, it must be given by lateral support or trussing, hence it is a common practice to tie or strut every angle pole; but when staying or strutting are impossible, as, for example, in the case of a pole in a waterway where lateral support cannot be given, and a transverse load cannot be avoided, then adequate stiffness must be bestowed by increasing the depth of the pole; this is sometimes done by coupling two or more poles together. As in every other structure adequate stiffness is necessary, and the stiffness as well as the strength of a pole should be considered in applying it, it must depend on the manner of its employment to what extent transverse stiffness can be dispensed with; if every angle pole is to be stayed or strutted, and transverse load on simple poles carefully avoided, an absence of stiffness may be permitted, which would be dangerous if the simple poles were to carry transverse loads on curves and at slight

angles. Other considerations—*e.g.*, portability, power of resisting oxidation, and cost, have to be considered in designing poles; but upon the stiffness depends the resistance really available, and this available resistance is an essential element in considering the value of any pattern. That load the pole will bear without suffering such distortion, permanent or temporary, as to render it unsafe or unsightly, is the measure of its strength in practice. If a transverse load has to be borne, a small set may be admitted, but not an increasing set, and in all cases the stiffness as well as the strength of the pole should be known. Pliability considered apart from any consequent set is a convenient quality, as its existence causes the strained body to indicate by its flexure when the actual load is too nearly approximate to the ultimate or proof load, and thus by giving visible notice of overloading it offers the opportunity for avoiding actual failure; a brittle body on the contrary offers no visible means of judging when it is overloaded, excepting by actual failure; but pliability is in itself a source of weakness and inconvenience, and beyond sufficient to give due notice of impending failure, should be dispensed with as far as possible. Other conditions being constant the stiffest structure is as a general rule the strongest. The following examples will illustrate the above:—A bamboo has sufficient strength to admit of its use as a telegraph pole, but its pliability is a source of insecurity; for its vibration under the action of a strong breeze may either lead to failure, or so loosen the post in the ground as to render it unsafe. The employment of bamboos in India is confined to temporary purposes, but if a temporary line has to be erected on bamboos (excepting when to be watched by a working party and required only for perhaps twenty-four hours), the bamboos are used in pairs, tied together to form shears which are placed across the alignment, this arrangement being required to obtain sufficient stiffness for safety. It is evident pliability should be limited, that posts which would wave in the wind like trees would be very inconvenient in use, for if not injurious to the post itself, such vibration would be injurious to other parts of a line of telegraph, and seriously affect the permanence and efficiency of the whole structure, particularly during storms. Other points in which extreme pliability would be very inconvenient will readily suggest themselves—*e.g.*, a post should be stiff enough to admit of a ladder being used against it, and to resist in a great measure a shock from a wheel or a large animal.

328. The following moduli of elasticity are given on the authority of Professor Rankine:—

	Ultimate Tenacity.	Modulus of Elasticity.
Good bar iron—average, .	60,000	29,000,000
„ plate iron— „ .	50,000	24,000,000?
Iron wire— „ .	90,000	25,000,000

By means of the above table the modulus of resilience may be calculated; for any other quality of iron the modulus of elasticity may be obtained as explained in Paragraph 51, and the modulus of resilience calculated from the tenacity and elasticity as explained in Paragraph 57. Another author states the elasticity of unannealed iron wire at 50° F. to be 26,467,700; at 5° F., 25,230,500; and annealed wire at 212° F., 28,418,600; the specific gravity of the wire was 7·553. The same author found iron, specific gravity 7·757, between 59° F. and 5° F. to have a modulus of elasticity = 29,569,000.

329. The fastenings used to connect ironwork are rivets, bolts, pins, wedges, screws, and keys. Rivets are, as a rule, preferred to bolts because, being applied hot, and hammered to form the head, they more completely fill the holes, and the shearing stress is distributed more nearly uniformly over the cross section of the rivet; but for great loads, as in joining the flanges of masts, bolts are preferred, being more easily applied. Pins are very generally employed to connect the parts of ties; keys are very generally used to fix wheels and barrels on axles, for keeping pins in place, &c. Screws (excepting as screw bolts) are not in common use as fastenings, excepting for small work; in construction bolts are preferred, but screws are commonly used in ties for adjusting them. If fastenings are subjected to shearing stress only, as with rivets, and commonly with bolts, then they must be proportioned to resist this stress only; but unless they actually fit the holes made to receive them, all such fastenings require to have their sectional areas increased in the ratios given in Paragraph 100, beyond the area actually necessary to allow sufficient resistance to a uniformly distributed shearing load, for the stress is not in this case uniformly distributed, it has its maximum through the axis of the fastening. The distance between the centres of contiguous rivets is termed the pitch of the riveting; if the bars or plates riveted together are to suffer tension, then the sectional area of the rivets should be equal to that of the plates or bars after punching the holes, the resistance of good rivet iron to shearing being equal to that of plates to tension; if the riveting is to suffer longitudinal compression the rivets may be placed nearer to each other than is indicated for tension, for in this case they do not weaken the work, and by pitching them close the plates are prevented from separating by buckling between the

rivets when compressed. As, however, the plates may be injured by punching, very close pitching is avoided excepting with very thin plates. For plates less than half an inch in thickness the diameter of the rivets is usually equal to twice the thickness of the plate, for thicker plates about once and a half the thickness of the plate, and for very thick plates sometimes only once that thickness, but never less; the length of rivet allowed for clenching is equal to two and a half diameters. From the above it follows that in a single riveted lap joint, the plates being less than half an inch thick, the most economical disposition of material is obtained by using a pitch of three diameters, and the distance from the centre of the rivet to the edge of the plate on each side should be equal to the pitch. In double riveted joints the rivets are arranged in a zig-zag along the joint. In chain riveting the rivets are arranged in files at right angles to the line of the joint; the joint is therefore generally wider than in other kinds of riveted joints. By placing the rivets behind each other the sectional area of the plates is not so much reduced as in the other modes of arranging them; the sectional area of the rivets is determined as in other riveted joints. A common form of joint when chain riveting is employed, is the butt joint with covering plates; but it is manifest the weakest section of such a joint is through the rivet holes—the joint is only as strong as the section of the plate joined measured through the rivet holes. As rivets fill the holes the shearing stress may be considered equally distributed over the cross section of the rivet, but when the work is loaded longitudinally the stress is not uniformly distributed over the section of the plates at the joint, the stress being communicated through the rivets, and not at every part of the joint, as in a welded joint; in a single riveted joint the resistance is reduced by one-fifth by unequal distribution of the stress. The commonest form of screw is that with the triangular thread; a better form for acting in one direction, as in bolts, would be that with one surface perpendicular to the pressure and the other surface inclined, the section being a right-angled triangle—wood screws are sometimes made in this form. The square thread is used as a rule only in screws intended to work both ways, as in vice screws; it is more durable and less liable to injure the nut if excessively strained or improperly inserted, but it is not so strong as the triangular thread; screws with the edges of the thread and groove rounded may be considered as a compromise between the triangular and square forms. Screw threads may be considered as very short cantilevers; they suffer a shearing stress, and the length of the nut should be such that the ultimate resistance of

the thread to shearing may be at least equal to the tenacity of the bolt; it should not be less than one-half the least diameter of the bolt, but in general it is much more. Screws used for pressure, as vice screws, should have long female screws to equalise the wear between the two screws. The tenacity of a bolt is the tenacity of the diameter measured between the screw threads. The pitch should not as a rule be greater than one-fifth the least diameter, and may be much less; the projection of the thread is usually half the pitch. The head of a bolt is usually about twice the diameter of the neck, and its thickness somewhat greater than half that diameter. Bolts when overstrained usually fail at the commencement of the thread, as this section divides the bolt into two parts differing in torsive stiffness (Paragraph 108), in the inferior bolts used for insulator brackets this mode of failure is very common; several modes of removing this source of weakness have been proposed—*e.g.*, making the neck of the bolt uniform with its least diameter and making the neck hollow, these expedients are not generally applicable; if the depth of the groove be made to decrease gradually towards the neck, the same end is attained, and in all bolts of inferior quality this point deserves consideration. The author has seen many bolts, of the quality used with the ordinary malleable iron bracket, twisted in two by means of a short wrench, and has known telegraphic communication to be interrupted by the failure of such bolts in the manner described. Mr. Kirkaldy found good wrought-iron screwed bolts were not necessarily injured, although strained nearly to the breaking point; those made with old dies were more tenacious than those made with new dies, being more hardened; that the tenacity of bolts of different sizes was as their areas, the smaller sizes being but slightly proportionately stronger than the larger; case-hardened bolts (Paragraph 343) were less tenacious than those of iron only, the greater tenacity of the thin steel skin was more than counterbalanced by the greater ductility of the iron. As already stated, common bracket bolts are rendered unsafe if over-strained. Bolts and other fastenings when to resist tension must be proportioned to this tension, and may in general be smaller than when required to resist shearing only. In order that keys or wedges may be safe against slipping out of their seats they must have stability of friction—*i. e.*, their angle of obliquity must not exceed the angle of repose for clean metal surfaces, this is about 9°, but to allow for the surfaces being greasy the angle is usually limited to 4° (Paragraph 49).

330. In designing joints, the relation between the dimensions and pitch of the rivets or bolts, and the dimensions of the work

should be so fixed that the fastenings may be equally distributed over the whole work, and the holes be so placed that there may be no fear of the fastenings being torn out; countersinking of rivet heads or flattening of them down should be avoided when possible; countersinking is only admissible in thick plates, and can, as a rule, be dispensed with in telegraph construction. In conical tubular poles fitted together in segments, as in Hamilton's poles, several rivets have to be clenched very flat; the author never heard of failure of an ordinary pole at these rivets, but in tall poles (*e.g.*, 40 feet) made on this plan such rivets are a source of weakness, and the author has known instances of failure (the posts were not supplied by Messrs Hamilton and Co.) at these flattened rivets. When rivets have been clenched with a hammer, the metal is shaped by means of a die termed a snap; if a rim of metal be formed by the snap, this may be cut off with a chisel, it is better however to leave it on, as there is risk of damaging the plate in removing it. Punching is more generally employed than drilling for making holes for fastenings; drilling is more expensive, but it damages the plate less, and is therefore preferred; but in punching an exceptionally brittle plate is broken, and the weakness due to punching may be removed by annealing. Punching is only applicable when the diameter of the hole to be made exceeds the thickness of the plate; if it be less, the hole *must* be drilled. If the holes to receive fastenings are not made exactly opposite each other, an instrument termed a *rhymer* is used to enlarge the hole; when this instrument is used, as is the case sometimes, to remove the effects of careless drilling or punching, it is objectionable, and engineers sometimes specify therefore that it be not used at all; but when used to smooth the holes, due care having been taken in making them, there is no objection to its use, in fact it becomes beneficial. The lap joint is inferior to the butt joint with butt covers, particularly when compression is to be resisted it is not so well suited for making plate iron cylinders, as it necessitates a slight departure from the circular section by which there is a considerable sacrifice of resistance to lateral compression. Butt joints may have one or two covering plates; the edges of the plates to be connected should be planed or cut true, and if they do not quite meet at any part the joint may be filled in with zinc—the work should be heated and melted zinc run into the joint. In connecting plates or bars to form structures, they should break joint as much as possible. Masts should be in as few segments as practicable, the best mode of joining these segments is by bolts through flanges, the flanges being carefully faced true; that mode of joining in which one tube is fitted

tightly inside another is inferior in strength and stiffness to a flanged joint, particularly in thin tubes, for in such cases the angle-iron flanges greatly increase the resistance both to a transverse load and to lateral compression (Paragraph 334). Bars for stiffeners, covering plates, &c., should be forged to shape, and not bent cold. Two pieces of soft wire may be joined by a lap joint bound with thin wire; if the binding be put on with a mallet a short joint may be readily made as strong as the uncut wire. An eye may be turned on a wire by bending the end round and binding with thin wire. Eyes are sometimes turned on wires by simply twisting the end round the wire itself, such eyes are very deficient in strength, they are liable to slip, and the bending frequently renders the wire unsafe; if the eyes be made by using binding wire, single wire ties may be safely used. The ordinary joints used for joining wire are described in another place. Ties of wire rope may be spliced as hempen ropes; if the wires be thin an eye splice round an iron form or dead-eye is said to be the only mode of turning an eye in which the joint is as strong as the rope; in making this splice a serving of wire is put on above and below the splice. Eyes are frequently turned on rope ties made of *thick* wire by twisting the wires forming the strands separately round the rope, this is applicable to thick wire only; the eye is turned and the strands being separated each is successively laid between the strands of the rope for a short distance, closely twisted three or four times round the rope, and its end cut off; the several strands should be finished off about 6 inches apart, the last should be twisted close to the eye. This mode of turning an eye is not suited to rope in which each strand consists of several wires; probably the best mode of making an eye in this case, when a splice is inadmissible, is to separate the strands of the end, lay them between the strands of the rope for some distance, and put on a tight serving of thin wire with a mallet. Some authorities state precautions to be observed in serving on binding wire; if such servings be put on with the mallet the fastening of the ends requires no special precautions, excepting to secure neatness. When the binding wire is soft there is no fear of it springing to an extent likely to render it unsafe if one end be bound in the serving and the other laid under a strand; if the wire be not stranded the ends may be turned in, or wound three or four times round the single wire. If the serving be put on by hand it is very inferior, as the wire is not stretched on or killed unless care be taken in securing the ends it is liable to spring loose.

331. Angle iron of various forms is used for simple struts; built struts are made of various forms of section by fastening

together bars of different sections, or bars and plates. Formulæ for calculating the strength of struts are given in Paragraphs 77, 78, and 80. The commonest kinds of tie in telegraph construction is the cylindrical rod and the wire rope. The rods are linked together by pins passed through eyes; the thickness of the pins and the metal at the eyes should be calculated by the rules stated in Paragraphs 96 and 100. Iron rod ties are less liable to be rendered unsafe by corrosion than wire ropes, and they should be used in preference when to be buried; they may be used in continuation of wire ties for the part to be buried. Hooks in iron ties are unsafe, unless made very heavy their use should be avoided. Plate-iron ties are joined by riveted joints or pins; they are seldom, if ever, used in telegraph construction. Wire ties are the strongest ties for their weight, unless the wire be annealed (the commonest case in practice), they are then no stronger than good soft iron rod. Chains are used as ties for stays, temporary lashings, &c.; they are of two kinds, open link or crane chain, and studded link or cable chain; the former is that used for cranes, stays, and lashings, the latter is used for marine purposes. Oval linked chain is seldom used larger than of one inch diameter iron; it is weaker than studded chain in the ratio, according to Barlow, of 85 : 100, and to other authorities 7 : 9 nearly; the effect of the stud is to cause a more uniform distribution of the stress over the cross section of the link. The strength of studded chain is about seven-ninths of that of the iron rod of which it is made, which, as already stated, may vary from little over twenty to twenty-six tons per square inch. Iron ties are commonly made of pieces of line wire; these are sometimes twisted together by passing the wires through holes in a thick board, and turning the board round in a plane at right angles to the wires, so as to twist the wires together, moving the perforated board along as the rope is formed behind it; this practice is not a good one, as the twist is uneven and the load on the finished rope is not distributed equally between the strands. The best mode of forming a wire-rope tie is the following:—Stretch wires to form the strands, and cut them to the same length; when they are straight they should be fastened to a board or iron plate at each end, if only two wires are used iron bars may be used at the ends; the wires being kept tight, they are twisted together by turning the boards or plates to which the ends are fastened; should a strand rise, it is beaten down immediately; when practicable the wires should move freely in the holes through the end plates to avoid twisting the wires individually; the tension during twisting by stretching the wires prevents them from springing when liberated. When a tie is

to have many strands it may be made with an eye at each end, as follows:—Pass the wire round two strong pickets until sufficient has been payed on to make the tie, bring the two ends midway between the pickets, stretch the wire tightly round the pickets, and again after paying it on by removing one of the pickets from the ground and hauling on it with a tackle; if this picket be caused to revolve, the wire being kept stretched, the whole is formed into a tie. The ties described above as made from wire are commonly used with ordinary sized poles; the last described is weakest at the eye, but is applicable in cases where neatness is desirable, and a little extra material is of no consequence. The ordinary thick wire tie used without a dead-eye should have the eye flattened to prevent the tie stretching from this cause. Thick wire ties may be partially buried, but thin wire rope should not be buried, and it should be protected from oxidation, particularly when in galvanised wires the zinc coating has been damaged in making a splice; a mixture of oil litharge and soot, oil paint, coal tar, or hot oil, are materials used to protect thin wire ties. Wire ties are sometimes made by placing wires parallel and binding them together at intervals; great care is necessary to distribute the load over the whole section of such ties, and their use should be avoided. In twisted ties the load is uniformly distributed without special care, provided the twist be not too long, if the twist be too long the wires do not act together, if too short they are injured, small sized wires require a shorter twist than large wires. Oval linked chain may be used for heavy ties or stays, as in staying standing masts, but being heavier than the wire tie the latter should as a rule be preferred, and invariably for long stays to high masts. Ties are tightened in various ways, the commonest being the insertion of a screw and swivel; post ties may be tightened by inclining the pole slightly towards the tie, fixing the anchor, and then pulling the post up to the vertical. A simple mode of adjusting ties is to push the collar up the pole, and fix it up by a wedge driven between the collar and pole from below. Wrought iron is subjected to transverse loads in the forms of flanged girders and tubes; the flanged girder may be either built up of plate and bars of suitable section connected by rivets, or rolled in one piece; for very short beams, as for supporting small platforms, and for the roofs of iron cable sheds, angle or T iron is employed. When the section of a flanged girder approximates to the strongest form—*i. e.*, the compressed and extended flanges have areas inversely as the resistance of the material to compression and tension respectively—its strength may be calculated with sufficient accuracy for practical purposes by Mr. Hodginson's

rule, expressed as follows:—The beam being supported at both ends and loaded in the centre, the breaking weight in tons = area of bottom flange × depth × constant ÷ length between the supports; the dimensions being stated in inches. The value of the constant for wrought iron when the web is very thin, as sometimes occurs in built beams, is 60, when the web is stiff 75. Mr. Hodgkinson has given formulæ for tubular girders, but the following approximate formula is sufficient for most purposes in practice:—$W = \frac{adc}{l}$ ...(1). W is the ultimate load, a the cross sectional area of the material of the tube, d the diameter of the tube, c a constant determined for each form of section by experiment, and l is the distance between the supports. The formula applies to girders loaded in the centre; the ultimate load of a cantilever of the same cross section and length, loaded at its outer extremity, is one-fourth of W in the above formula (Paragraph 124). The value of c represents the relative strengths of different forms of cross section—*e. g.*, the Siemens' tube being assumed to fail at the ground line with a leverage of 17 feet, and an ultimate load of 560 lbs., as stated by the maker, its constant is nearly 33; the Hamilton tube diameter 7·75″, being assumed to fail with an ultimate load of 500 lbs., applied with a leverage of 14·5 feet, has a constant of 19·5—the leverage is probably overstated. The numbers 33 and 19·5 represent the specific resistances of the two forms—*i. e.*, if containing the same mass of material the strength of a Siemens' post would be 33, while that of a Hamilton post would be only 19·5. As explained in Paragraph 327, stiffness has to be considered, the *available* strength not the ultimate resistance is that with which the engineer is most concerned. The above figures are given merely as illustrative examples; the data are copied from circulars, and the author knowing nothing of the mode in which they were obtained does not state them as facts for guidance. If the constant c be determined by experiment for any form of beam, then the strength of any similar beam may be calculated by the equation (1). The experiments made to determine the best form of tube for tubular bridge girders shewed the constant c for thin iron cylindrical beams to be 13 tons, the thickness of metal being very small compared with the diameter. Substituting this value for c in (1), the strength of a wrought-iron plate cylindrical pole may be calculated, the pole being regarded as a cantilever. The thickness of the plate must be small compared with the diameter of the pole; hence the area of the material is very nearly equal to $\pi d \times t$, in which t is the thickness and π the ratio between the circumference and the diameter of a circle—hence, from (1) the

strength of such a pole regarded as a cantilever is given by the equation—

$$w = \frac{d^2 \pi t}{4l} 13 \text{ tons} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.)$$

By means of the above formula (2) either of the quantities $d\ t\ l\ w$ may be found, the others being known. (See also Chapter II., section 6.) Iron beams are fixed only at one point to allow for expansion and contraction with changes of temperature; iron telegraph poles being stayed with iron stays, the expansion of the stays is sufficient to allow for expansion of the pole, thus no such special provision is required. When girders are lifted into position they are frequently stiffened temporarily with timber; telegraph masts of thin sheet iron may require similar provision to stiffen them while being raised. As a general rule, the heel of the mast should not be lifted from the ground, and the mast should be seized at two points, and not by the head only; if the mast cannot be lifted with these precautions it is probably too weak. Should it however be necessary to stiffen it, a good plan is to fill it with bamboos, or other light cheap endogenous wood procurable near the spot, or lash on a light spar outside.

332. Telegraph masts of wrought iron differ widely in pattern; for large masts, standing masts built on the same principles as the wrought iron lower masts of ships are probably the most economical. These are made of bent plates, each plate usually forming an arc of 120°; the plates are connected together by through riveted lap joints, or butt joints with covering strips; the masts are usually stiffened by continuous T or L iron in the direction of the mast's length, attached inside, and frequently serving the purpose of covering strips to the longitudinal joints. Iron masts are usually built the same diameter as wooden masts; they are as strong as wooden masts if well built. Large-sized iron masts are less costly than wooden ones, but for small masts wood is cheaper, unless it has to be transported a great distance. The lighter patterns of iron masts are nearly one-third lighter than similar masts of wood; but if with a strong system of stiffeners, as applied in the Royal Navy, the large masts are about as heavy as wooden masts of the same size, and in small sizes iron masts are heavier than wooden ones—the cast-iron earth tubes used for telegraph masts are excluded. The iron masts used in the Royal Navy are more costly than wooden masts, but being stronger and much more durable, they are more economical and more reliable. In most situations iron masts of large size, built as for merchant vessels, would be as cheap as good

pine masts, and far more economical; but where a good durable wood can be bought cheaply, whereas ironwork must be transported a considerable distance, wood may be much cheaper than iron—this is more often the case with smaller sizes up to say 50 feet than with larger. Telegraph masts may be stiffened like the masts used in the Royal Navy, when they are required to resist the action of a considerable transverse load, and lateral support cannot be applied; or in such cases the circular section may be departed from and the mast built as a cantilever, with its depth greater than its width. Such cases occur very seldom indeed, and in general a telegraph mast should be less costly than a ship's mast, for the plates may be as a rule somewhat thinner, the rivets are not required to be countersunk, and whenever practicable, one standing mast should be preferred to a standing mast surmounted by a running mast, thus dispensing with the mast-head fittings. The plates of lower masts in the Royal Navy vary in thickness between $\frac{1}{4}''$ and $\frac{5}{8}''$; in the largest masts there are sometimes four plates in the circumference, but more generally three, and in small masts only two. The "Bellerophon" lower masts, for example, are of $\frac{7}{16}''$ plates, three to the circumference, of "best best" quality, and at least twelve feet long; fig. 61 represents a section of one of these masts, the edges of the plates are single riveted, the ends are butt jointed, the joints being double chain riveted to the covering plates worked inside; the T bars are welded into one length when practicable, otherwise they are used at least 24 feet long, and joined with butt covers; the longitudinal T irons are $6'' \times 4'' \times \cdot5''$ in section, every 6 feet transverse stays of T iron $5'' \times 3'' \times \cdot5''$ are fixed to form a triangle, as shewn in the figure; great care was exercised in accurately fitting the butt joints and in arranging the pieces to break joint in the direction of the mast's length.

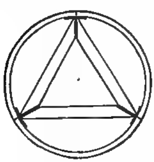


Fig. 61.

The diameters of these masts are—fore 33″, main, 35″. The following are examples of the construction of iron masts of merchant vessels:—No. 1, four plates to the circumference, joints double riveted lap, stiffeners continuous L iron worked on the centre of each plate. No. 2, three plates to the circumference, joints single riveted lap, stiffeners L iron worked on at joints with the joint rivets. No. 3, three plates in circumference, butt joints, T iron stiffeners worked on to serve also as covering strips to the edge joints. In some cases the stiffeners are dispensed with, and an addition made to the thickness of the plate, to compensate for their absence; horizontal stays of L, T, or plate iron, are sometimes inserted six feet apart, these serve also to climb

and paint the mast inside. The following dimensions are those prescribed in the Liverpool Underwriter's Registry:—

Length.	Diameter.	Thickness. Body.	Thickness. Head.
60 feet	20 inches	$\frac{3}{8}$ inch	$\frac{5}{16}$ inch
96 „	32 „	$\frac{1}{2}$ „	$\frac{7}{16}$ „

When angle irons are omitted an addition of $\frac{1}{16}''$ to be made to the thickness, and in lower masts not more than three plates are permitted to the circumference. The commonest kind of iron trestle trees are those formed of angle iron bent round, fig. 62, to form a socket for the topmast heel, and supported by plate-iron cheeks or knees. The contraction in diameter to form the mast-head is formed by fitting a smaller tube to the larger with angle irons and gussets inside and at the top, or by angle irons inside and out, as shewn in fig. 63, the inner tube is inserted in the outer for some distance. The system of construction applied in ships' masts is applicable to telegraph masts, the following modifications being made:—The rivets need not be countersunk, the strength required is not so great, running masts should be avoided as a rule, steps and handles or an iron ladder should be attached to the mast for climbing it. In most cases provision must be made for separating the mast into several pieces for convenience of carriage—thus it may be shipped in several pieces to be riveted together on the site of the crossing; the iron may be bent, drilled, and marked, to be welded or riveted on the site selected; the tubes may be made with flanges to be bolted together, or they may be joined by a socket driven over the thin end, or by an open socket bolted together through flanges. Masts up to 40 feet in length are sometimes built by fitting the ends of the segmental tubes into each other, as in the Hamilton pole, a set of tubes made by Messrs. Hamilton & Co., consisting of five segmental tubes each 8 feet long, and a cast-iron ground tube; these tubes may be used to form posts from 16 to 40 feet long, and the smaller posts may be made of several degrees of resisting power by using the larger or smaller segmental tubes with different sized sockets. The ultimate transverse load of the weakest combination of two tubes is 500 lbs., the post being considered as a cantilever, loaded at its unsupported end, and the strength of the combinations up to the extreme of 40 feet is 500 lbs.; the object in using a set of tubes two of which form the ordinary pole, is to have the means of obtaining by a suitable combination a post of any height up to

Fig. 62.

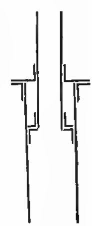


Fig. 63.

the maximum, and to furnish short posts of several degrees of transverse resistance—*e. g.*, the combination of the two smallest segments has an ultimate resisting power of 500 lbs., the transverse resistance of the C and D segments is 1500 lbs., each combination being about 16 feet long; another advantage of this so-called telescopic combination is that the tubes pack inside each other for convenience of transport. Tubes joined by insertion into each other are inferior to those joined by flanges or sockets, and this mode of construction appears applicable only to masts up to about 40 feet in length; about four is the largest number of joints which should be permitted in such a mast made of thin wrought-iron plate with lap joints, and no stays in the inserted ends of the segmental tubes. The principal objection to this mode of jointing would be removed if the inserted end of each tube were strengthened by stays or the insertion of a wide hoop, to resist the thrust of the outside tube when the pole is strained transversely; the collars used at each joint do not support the inner tube at all; in flanged tubes the flanges strengthen the tube both above and below the joint. Four pairs of masts varying in height between 75 and about 120 feet were erected to cross four rivers in Bengal; the basement tubes were of cast iron to above high-water mark, the wrought-iron portions were in 9 feet flanged segments, four strut braces projected from the mast at every alternate joint—*i. e.*, 18 feet apart, and from these the mast was trussed in the usual way by iron ties with adjusting screws; each mast had two tiers of stays, was surmounted by a cage a few feet below the insulators, and fitted with a vertical iron ladder from the ground to the cage. The flanged form is very stiff, and trussing is very seldom necessary in telegraph masts.

333. Iron wire is made by rolling the bar to a small section, and then drawing it down by passing it through drawplates. The wire is, as a general rule, annealed, and the tests applied to it usually have reference to its ductility and the absence of flaws; high tensile strength being incompatible with the requisite softness is not insisted on. The following are conditions usually specified, and the tests to which line wire is subjected :—

1. The wire to be in pieces of a minimum weight, to contain no joint within this limit, the piece being rolled and drawn from one piece of iron. This limit varies with the size of the wire; 30 to 40 lbs. is a common limit for the sizes in general use. The Indian administration specify coils of 95 to 105 lbs. for wire ·251″ to ·210″ diameter, and of 35 to 40 lbs. for wire ·072″ to ·067″ diameter; coils in one piece being preferred, but one joint permitted in each coil. The kind of joint to be used should be specified.

2. It is commonly specified that the wire be drawn through a minimum number of holes, as drawing is more beneficial than rolling; the number insisted on is commonly two, but it is generally drawn through a greater number.

3. The wire should be truly cylindrical and of uniform sectional area. As true uniformity cannot be attained, a margin is permitted, and this margin is usually specified. Ordinarily the weight of any given wire may vary 5 per cent. from the average; the Indian administration allows a margin of only 1·5 per cent. for sizes weighing more than 600 lbs. per mile, and 2 per cent. for smaller wires.

4. There should be no weld in either the wire or rod. It is usual to have the wire highly annealed; the degree of hardness should be as uniform as attainable. The surface of the wire should be smooth and even, free from scale, flaws, sand splits, and projections of adherent zinc. The wire is sometimes passed over and under a series of small pulleys to test it for faults such as cracks.

5. Certain tests for ductility are always specified; these tests are of different kinds, they may be classified as *elongation* tests, *torsion* tests, and *bending* tests. The elongation tests consist in stretching the wire a certain percentage of its length. This stretching may be performed directly by suspended weights, by hydraulic machinery, or by one or more levers; the Indian administration admit the use of suspended weights only, objecting to machinery as introducing elements of inaccuarcy, as friction; other authorities object to the use of weights, because the force is not added so gradually as when the pressure of water is used. The simplest hydraulic, or more properly hydrostatic testing machine, is one on the principle of the hydrostatic bellows, devised by Sir W. Thomson; it has neither springs nor valves, there is no sensible error due to friction, and the load can be added gradually; this machine is therefore preferred by some to the direct action of weights. The machine is described in the second volume of the *Journal of the Society of Telegraph Engineers*. As short bars may stretch more proportionately than long ones (Paragraph 86), the proportionate ultimate extension being specified it is necessary to specify also the length of the specimen of wire to be tested. It is probable, when the length of the rod tested is considerable compared with its thickness, as in wire, short specimens always stretch more proportionately than long ones, and the exceptions to this rule observed by Mr. Kirkaldy may disappear. Mr. Cully in 75 tests of a coil of wire, diameter ·165 inch, found pieces 10 inches long stretched 19·5 per cent., pieces 120 inches long stretched 12·7 per cent., and in a few pieces,

tested in lengths of 100 yards, the ultimate elongation was but little over 6 per cent. In two qualities of wire ·239 inch diameter, the ultimate elongations being equal, and in each case 18 per cent. when tested in lengths of 10 inches, when tested in lengths of 10 feet the ultimate elongations were—A 12·0 and B 9·0 per cent; and when the same wires were tested in pieces of 100 yards, the ultimate elongations were—A 5·5 and B 4·5 per cent. Mr. Cully found the time occupied in testing the wire materially influenced the results, the elongations being proportionately greater when the wire was stretched more rapidly; when the times were as 1·00, 1·73, and 3·11, the ultimate elongations were as 17·80, 15·40, and 13·80 respectively. The absolute time occupied in each case is not stated. Mr. Bell thinks the phenomenon may be explained by the softening of the wire consequent on the heat developed by rapid stretching; Mr. Kirkaldy has explained a decrease of brittleness in iron at 32° F. by the iron being *more* warmed by reason of the load having been applied *gradually*. Mr. Kirkaldy found the contraction of area *less* with a suddenly applied load. It is to be regretted Mr. Cully has not stated the absolute time as well as the relative time, the appearance of fracture, and the ultimate tenacity in each case, and that he has not given other than average figures; for if these particulars had been given, the results might have been considered with those obtained by Mr. Kirkaldy and others, and a nearer approach made to a theoretical explanation or the discovery of a law. It should be remarked, although the heat developed be the same whether the iron be stretched rapidly or slowly, in the former case the temperature of the wire would be raised more than in the latter, for the total heat being developed in a shorter time less would be lost by radiation. In general the elongation test is applied to pieces 10 inches long, and an elongation of 18 per cent. is commonly specified in this length. As in the qualities referred to above as A and B, both stood the test equally well in lengths of 10 inches, but shewed a difference of ultimate elongation when tested in longer pieces, and as this difference was apparent in working with the wire, Mr. Cully concludes 10 inches is too short a length for general adoption in practice, and he considers ten feet a more suitable length to exhibit the quality of the wire. Assuming that the difference in quality was exhibited in handling the wire, but was not rendered apparent by the elongation test applied to a short piece, as stated by Mr. Cully, this would lead to the conclusion that differences of quality are more readily rendered apparent by a bending test than by an elongation test. Sometimes wire is tested by being stretched 2 to $2\frac{1}{2}$ per cent.;

it is passed several times round a drum, and is drawn off this drum by passing several times round a second larger drum, the relative diameters of the drums being such as to produce the elongation required. This process is also termed *killing;* the wire is somewhat hardened by the process and it is straightened. In India the wire is killed by being hauled up to half dip on erection; this load being kept on for a few minutes the spring is taken out of the wire, it is straightened, and if deficient in tenacity it breaks, or if the joints are weak they open; it is claimed for this mode of proceeding that the wire is handled while soft and not rendered harder until actually erected, and that the line joints and wire are tested together by one operation. *The torsion test* is applied by holding the wire in two vices a fixed distance apart, and causing one or both of the vices to revolve so as to twist the wire round its own axis; an ink line drawn on the wire previous to testing forms a spiral when the wire is twisted, and the ultimate number of turns in this spiral is the test of ductility—this is the test applied by the Indian Telegraph Department. Sometimes a machine is used which registers the number of turns. The ultimate number of turns in a given length a wire will bear depends on its diameter, the length twisted, and the time occupied in applying the test. Six inches is the length usually tested; the Indian Telegraph Department specifies 6 inches for wires weighing 150 lbs. and more per mile and 3 inches for lighter wires. The number of turns is approximately inversely as the diameter of the wire tested; Mr. Cully found the average of a large nnmber of trials was thirteen turns in a length of 6 inches of wire, diameter ·253 inch, and for other sizes was—

Diameter, .	·207 inch.	Turns in 6 inches, .	15·9
„ .	·146 „	„ „ „ .	22·5
„ .	·077 „	„ „ „ .	42·7

Manufacturers specify 12 to 18 twists for No. 8, and 40 to 50 for No. 20 B.W.G., in a length of 6 inches. The Indian Telegraph Department fixes both tenacity and ductility—*e. g.*, in wire ·251 to ·258 inch diameter the tests are as follows:—

Tenacity.	Ductility.	Tenacity.	Ductility.
Lbs.	Turns in 6″	Lbs.	Turns in 6″
2,775	14	2,925	12
2,850	13	3,000	11
		3,076	10

In cable wire one turn less is required for the same sized wire having the same tenacity. The time occupied in testing by the torsion test has very little influence on the result in practice; Mr. Cully found when the speed of turning was as 10 to 25 the number of twists was as 14 to 14·3. It appears the torsion test is more reliable than the elongation test, as it is less influenced by time and appears to exhibit differences in quality more readily and with greater certainty. Mr. Cully obtained the following results:—

	Diameter.	Elongation.	Twists in 6″.
Ordinary wire, .	Not stated.	17·4 per cent.	12
,, ,, .	·234 inch.	17·6 ,,	10
Charcoal ,, .	Not stated.	17·0 ,,	18
Homogeneous ,, .	·253 inch.	17·6 ,,	13

It is to be regretted Mr. Cully has confined himself to stating average results; in an inquiry of this nature knowledge of extreme results is essential to a just conclusion, and statement of the element of time is essential. Another mode of testing wire is by bending it—it may be fixed in a vice and bent backwards and forwards to a right angle in each case, until it breaks; it may be bent and hammered up closely against itself, in which case the bend should shew no signs of failure; or it may be coiled closely several times round itself. These tests have the advantage of resembling the treatment the wire is subjected to in use.

6. Line wire is usually delivered as it comes from the testing; it is coiled into close coils of a specified weight, being joined when necessary by the usual soldered joint; it should not be at all crooked, but even, closely coiled, and bound with thick binding wires preferably put on hot. Thin wire only is packed in boxes or drums, ordinary line wire is shipped in coils.

Cable wire is used harder than line wire—a higher tenacity, lower ductility, and longer pieces are usually specified—*e.g.*, the Indian Telegraph Department specification does not admit joints in cable wire coils weighing 95 to 105 lbs., the size of the wire being ·204″ to ·258″ diameter. Wire is usually distinguished in size by numbers, the scales used being known as the Birmingham and Whitworth wire gauges respectively; by French engineers and sometimes in England the diameter in millimetres is used, and in England the diameter is frequently stated in thousandths of an inch. The Birmingham wire gauge scale is that generally used, but this scale is indefinite, differing according to the maker; authorities differ as to the exact diameter of the different sizes, and in the smaller wires this difference is considerable; some of these differences are shewn in the table, Paragraph 319;

in Nos. 20 and 21 this difference amounts to one size, some makers designate a wire ·035″ diameter No. 20 and others No. 21. When accuracy is requisite the diameter of the wire should be stated as a fraction of an inch, there being no generally accepted scale to which it can be referred. By reason of the Birmingham wire gauge being indefinite, its use is felt to be productive of much inconvenience, and will be discontinued in favour of another scale, probably the Whitworth scale (described below), but at present there is much uncertainty and difference of opinion concerning the relative merits of the several scales proposed. It has been proposed to take a standard wire (No. 16, authorities agreeing in stating its diameter), and refer all wires to this standard. Another proposal is to use a scale in which No. 1 represents a wire weighing 25 lbs. per mile, and taking this as a standard, No. 2 weighs 50 lbs., No. 3 75 lbs., etc.; this scale has much to recommend it, being exceedingly simple and practically useful—it is used for line wire in India. The Indian authorities use the Whitworth gauge, but recognise only the gauge by weight, and specify that in case of dispute as to size a length of 10 feet is to be weighed. Mr. Whitworth has proposed a decimal scale, the difference between the sizes being a regular number of thousandths of an inch; this scale is in use. In this scale, termed the *Whitworth Standard Decimal Gauge*, No. 1 is the same size as No. 1 B.W.G., viz. diameter ·300 inch; the sizes decrease in diameter by regular decrements of ·020 inch to No. 7 diameter ·180″; the diameters are then as follows :—

No.	Diameter.
8	·165 inch
9	·150 „
10	·135 „
11	·120 „
12	·110 „
13	·095 „
14	·085 „
15	·070 „
16	·065 „
17	·060 „
18	·050 „

The several scales proposed are arranged to approximate closely to the present scale (B.W.G.), in order to avoid as far as possible the inconvenience consequent on change of standard. The system of distinguishing a wire by the weight of a mile has been partially introduced in the case of copper wire, it is sufficiently accurate for ordinary use in construction; wire is bought and its transport

paid for by weight; its weight enters into calculations of tension of land lines and cables, and electrical conductivity is directly proportionate to weight; but a wire gauge should be applicable to all purposes, and the decimal gauge appears that most generally applicable in engineering works and accurate investigations. It is usual to state the diameter of the wire or its area, and continental authorities distinguish wires by their diameters, wires have to be drawn with reference to diameter necessarily; while the use of the weight rather than the diameter as a basis for the scale the space being imperfectly defined is objectionable on scientific grounds. The real object of a gauge is to distinguish not mass but volume; a statement of the volume conveys a distinct idea of the wire—*i. e.*, whether thick or thin, easy or difficult to work, &c., the quantities considered being small, readily appreciable by the senses, and closely associated in the mind in the complex idea. The statement of one dimension and the weight does not convey a distinct idea, the connection between the ideas of weight and length being far less close than that between those of length and transverse dimensions, and the quantities considered (one mile in length and its weight) are too vast to be appreciable by the senses—*e. g.*, diameter ·251″ conveys a more distinct idea of the wire than the statement that one mile weighs 900 lbs. These considerations have led to the general adoption hitherto of gauges by diameter rather than those based on weight—it appears better to strictly define the volume than to introduce the mass. The cross sectional area in square inches multiplied by ten is the weight of a yard in pounds, a cubic foot of iron being assumed to weigh 480 lbs.; and the relative weight of different sized wires is as the squares of their diameters; hence, from the volume may be readily calculated the weight with sufficient accuracy for ordinary purposes. Stranded wire is very generally used for town lines and long spans, it is made either of three or of seven wires. The advantage of using stranded wire appears to be due to the fact that several thin wires are more flexible, and will bear bending better, than one wire of equal sectional area and degree of hardness; hence, in the stranded wire a greater degree of hardness, and consequently higher tensile strength are admissible, than in the single wire. Telegraph wire is, as a rule, made of "best best" quality iron; sometimes inferior quality is used for binding to insulators, but as a rule, good quality wire is the most economical for all purposes.

334. Wrought iron is used for fastenings, both for wood and brick and stone; it is better suited for connecting timber than cast iron, being more like timber in its mechanical properties. For cramps for stonework it is inferior, as it is more

liable to corrode, and by its expansion split the stones. Its liability to corrosion renders it inferior to cast iron when to be buried in the ground, and when possible structures of wrought iron should have plinths of cast iron, stone, or wood, to which they may be attached by bolts or otherwise. Wrought iron huts built of continuous or corrugated sheet iron and angle and T iron are very often employed for cable huts in situations where difficulty is experienced in getting a durable building erected by labour and of materials found near the site. These huts are somewhat expensive as a rule, much more so than huts of matting and bamboos, planks, bark, or other perishable materials; but they are fire-proof, they do not require frequent inspection to insure their safety, they are very durable if placed well above high-water mark, and if kept painted they can be removed from any place where no longer required—a great advantage when used for river cables, as when a cable fails the new cable is not always laid in the same situation as the old one was. A hut is not always used to contain the junction of land lines and cables, a hollow post serves the purpose equally well; but when the offices on a line are far apart, and travelling difficult and slow, as in India, the hut serves as a storehouse for tools and materials, as a testing station, a rest-house, and when the river cable fails as a temporary office; the messages are received and despatched at each bank hut, and conveyed between the two huts by boats. The huts are 8 to 10 or 12 feet square, usually bolted to balks of timber (white ants not attacking wood in such situations) to form a foundation; but as the foundation is merely superficial (Paragraph 250), the ground is liable therefore to be disturbed. In exposed situations on banks of made earth the foundation should be deeper, or three or four ties should be thrown across the roof and anchored on each side, in the same manner as pole ties, they may be furnished with ordinary adjusting screws. A hut tied down sinks with the earth, but cannot be overturned; without such precaution if the bank be injured by heavy rain and flooding, the hut may be destroyed by a violent storm, the weight of the structure being insufficient for stability under such conditions. Wrought iron is used in preference to cast iron when required to be long compared with its lateral dimensions, and at the same time strong; thus insulator stalks, stays for chimney stacks, long light arms for insertion in brickwork, &c., are preferably made of wrought iron; cast iron being weak is inapplicable, but malleable cast iron is now used for many purposes to which wrought iron was applied formerly, particularly for small thin masses. When the wire is suspended by the insulator stalk the latter is generally

of wrought iron, sometimes of steel; cast iron has been used for stalks supporting insulators, but the material has been found unsuitable, and wrought iron is the material now almost invariably employed. Short wall brackets to carry two insulators are usually of malleable cast iron, but long brackets should be of wrought iron; many post fittings, as pole roofs, lightning dischargers, &c., are of malleable cast iron; but long thin fittings, as shackle straps, should be of wrought iron. Tools, excepting the smallest cutting tools, are of wrought iron edged with steel; small cutting tools commonly have shanks, bolsters, and tangs of iron. In all tools care should be taken to have a sufficient mass of steel in the edge to admit of the tool being repaired and sharpened; in India good rough tools may be obtained in the villages, but they contain so little steel they are soon worn out (unless made to order under supervision). Care should be taken to keep all iron tools well steeled.

335. The commonest modes of preserving ironwork from corrosion are galvanising and tinning (Paragraph 311); the coating should be smooth and even, and it should not spring off when the metal is bent; to ensure adhesion the iron should be raised by immersion in the metal to the temperature of the bath. When the zinc has been removed from a galvanised wire in cleaning it before making a joint, the whole surface denuded of zinc should be carefully tinned before binding the joint. Drying oil is sometimes used as a surface protector for line wire, because less costly than galvanising; it should be applied hot, or the iron should be heated. Oil paint is commonly used, and several kinds of paint, termed "anti-corrosive" by the manufacturers, are sold for application to ironwork. For paint to adhere well the surface of the iron should be rough, but before painting all loose scale should be scraped off. Whenever practicable ironwork should be of such design that the whole surface may be examined and approached for cleaning and painting; men engaged painting inside work with ordinary lead paint should come out at short intervals, as the vapour from the paint in a confined space may cause fainting and sore eyes. Other preservatives used for ironwork are tar, various mixtures of tar and oil, and black varnishes. For small work Paris enamelling, ordinary varnishes, and lackers used thin, the iron being warmed, and for fine cutting instruments mercurial ointment are used; cutting tools packed for export may be painted. When in store iron is more liable to rust than when it is in use, vibration being a powerful preservative; therefore ironwork to be kept long in store, particularly tools, should have a temporary protective coating.

336. Cast iron is for many purposes inferior to wood, or

altogether inapplicable to purposes to which wood is applied, being heavy, brittle, and not admitting of use in thin plates, as is the case with malleable iron; malleable iron may be used to supersede wood in almost all cases, and in most cases with great advantage, its greater cost being in general the cause which militates against its adoption. The principal advantages possessed by iron over wood as a material of construction are the following:—Iron may be made into any form which gives the maximum strength for a given mass of material; therefore, as a rule, structures in iron are lighter than similar structures in wood, this is particularly the case when the structures are of large size. Structures in iron are more readily transported, because they may be made in hollow pieces to pack together, they may be made in smaller pieces than timber structures, and they are commonly lighter. Structures in iron may be erected, taken down, and re-erected without injury. Ironwork is not so liable to hidden defects as wood, and it is more durable; it is safer because its mechanical qualities are not liable to be changed by excessive dryness, heat, and moisture, and it bends under a shock which might split wood. The joints in ironwork and the mechanical properties of the material are such that a structure in iron acts more like one piece than a collection of pieces; timber, on the contrary, cannot be joined so perfectly; a wooden structure overloaded as a whole separates into its component pieces, whereas a similar structure of iron is stronger, because if well constructed it can only suffer collapse as a whole. Iron is more expensive than wood in small structures, but in large pieces it is commonly less so—*e. g.*, in most situations a 20 feet pole of iron is very costly compared with a similar pole of wood, but a 100 feet mast may in most cases be built of iron at a less cost than it could be built for of wood. The cost of iron poles of ordinary sizes varies between three and five times the cost of similar sized wooden poles. The first cost and absolute durability of ordinary sized wooden poles are such as to make them in general cheaper than iron ones, hence they are so frequently preferred; it is a fallacy to assume iron is more economical than wood because its durability bears a greater ratio to the durability of timber than its first cost bears to that of timber; one author has asserted that timber poles last in some climates only two or three years, and under the most favourable circumstances rarely longer than six; reference to Paragraph 209 will demonstrate that this author has very much under-estimated the durability of timber. In India they certainly last much longer on an average, they also last much longer in England, and the author personally consulted two officers of the French Govern-

ment Telegraph Service on the subject, and they agreed in considering twelve years as the average life of a wooden post in France; M. Blavier's estimate is higher. In calculating the relative economy of iron and wood, it must be assumed the difference of cost in favour of wood is placed at compound interest at the current rate, and it will be seen that wood might possibly be the more economical, even if the iron pole lasted forever without deteriorating in value.

Division III.—Steel and Steely Iron.

337. Steel contains carbon in proportion intermediate between the proportion contained in cast iron and in wrought iron respectively. The processes of its production may be divided into two classes—in one the object is to extract the excess of carbon from cast iron, in the other to cause carbon and wrought iron to combine. Processes of the former class are employed for producing large quantities of steel for engineering works, and when the finest quality is not admissible by reason of its costliness. The product is inferior as a rule to that produced by processes of the second class, from the greater difficulty in ensuring purity in cast iron than in wrought iron; but it is less costly by reason of the comparative cheapness of the material employed, the greater simplicity of the processes, and the fact that it is produced in large masses suitable for working into plates and bars without previous working, to ensure homogeneity and weld small pieces together. Processes of the second class are employed to produce steel of fine quality, as for cutting instruments; and the best qualities of wrought iron are employed. Steel is produced by puddling (Paragraph 304), the process being stopped when the quantity of carbon in the cast iron has been sufficiently reduced to convert the cast iron into steel. It is produced by the Bessemer process (Paragraph 304) by stopping the process of conversion when the proportion of carbon has been sufficiently reduced, or by carrying it on until the whole of the carbon has been oxidised, and then adding carbon, with silicon and manganese, to the melted malleable iron. The treatment of the bloom or ingot produced is the same as that described for wrought iron (Paragraphs 304 to 306); and the steel produced is rolled or forged into bars, plates, or other forms, in the same manner as wrought iron. Blister steel is made from wrought iron by a process termed *cementation*, which consists in heating iron bars in a closed chamber for several days in contact with charcoal. The bars are not completely converted into steel, they have a skin of steel while in the interior they are wrought iron,

or only partially converted. The surface of the bars has a blistered appearance, hence the term *blister steel.* When a similar process is applied to articles of wrought iron, to give them a skin of steel in order that they may be highly polished or more durable, it is termed *case hardening.* Blister steel not being homogeneous, to render it so it is either worked or melted and cast into ingots. In the former case the bars are rolled together at a welding heat and the mass repeatedly worked, the product is termed *shear steel;* in the second case the blister steel is melted with a little additional carbon and manganese, and the product is termed *cast steel.* Cast steel is also made by melting wrought iron in a closed vessel with the proper proportion of carbon and some manganese. There are other processes for making steel, but they are either not so generally employed or the details of them have not been published. *Homogeneous metal* is intermediate in composition between malleable iron and steel; it is made by melting iron with a smaller proportion of carbon than is requisite to form steel, as described for making cast steel. Malleable cast iron is described in Paragraph 296. For blister and cast steel the purest iron is used; Swedish and Russian charcoal irons are extensively employed for the purpose. The composition of the steel can be regulated in manufacture according to the purpose for which required; for engineering works as a rule a mild form of steel is necessary, whereas for some kinds of tools a very highly converted steel is requisite. Good shear steel makes good tools —it is used for heavy rough tools and inferior quality cutting tools; but cast steel is better in appearance, and is used for the best qualities. Blister steel is used for files, rasps, and other tools; but generally cast steel is employed. Blister steel will bear a greater heat without injury when forged than cast steel; the latter is more difficult to weld than either blister steel or shear steel. Steel, like iron, requires to be worked to develop its strength; it is cast under pressure, and treated in a similar manner to cast iron, to prevent porosity and increase its density. Very inferior articles are sometimes cast of steel; the material is termed technically *run steel.* It is commonly termed *cast steel,* and the articles are made to imitate forgings of cast steel proper; not having been worked but cast, they are very deficient in strength.

338. Steel is distinguished by the capacity for being hardened and tempered. If raised to a high temperature and suddenly cooled by immersion in water, oil, or by other means, it is hardened; wrought iron is also somewhat hardened by such treatment, but steel may be made extremely hard, so hard as to scratch glass. The hardness of steel may be reduced by *tempering*

to any required degree of softness, almost to its original state previous to hardening. Tempering is performed by gradually heating the hardened steel and observing the changes of colour on a part of its surface rubbed bright for the purpose; the temper is designated by this colour. The first yellow visible indicates increase of toughness without sensible softening, a deeper yellow approaching to orange indicates the temper suited for tools for working metals, a deeper orange suited for wood-cutting tools, and blue for springs, white follows blue and indicates softening to almost the original state. Steel is stated to be tougher, if instead of being made very hard, and the hardness reduced, it be heated to a dull red only, and thus hardened to a lower degree so that tempering is dispensed with. Steel expands in hardening; the most highly converted steel hardens at the lowest temperature, and expands most. As steel is injured by heating unless great care be exercised, it should be hardened at the lowest practicable temperature; and as small objects may be more suddenly cooled, they do not require so high a temperature as larger ones of the same steel. Mr. Kirkaldy states, steel is reduced in strength by hardening in water, but its strength is vastly increased and it is rendered tougher by hardening in oil; the increase of strength is greater in the latter case the higher the temperature at which the steel is hardened, provided it be not burned, and in highly converted or hard steel than in soft or less converted steel. Steel plates hardened in oil and riveted together were found fully equal in strength to an unjointed soft plate; the loss of strength by riveting was more than counterbalanced by the increase of strength due to hardening in oil. The hardening of steel is supposed to be due to an action similar to that which takes place in grey cast iron when suddenly cooled, the hardened steel being regarded as analogous to granular white cast iron (Paragraph 296). The density of steel varies from that of the best wrought iron, about 7·75 to about 7·9; the more highly converted steel is not necessarily the denser; cast steel is much denser than puddled steel, which may be less dense than some of the best qualities of wrought iron. A cubic foot of steel may vary in weight between about 484 and 493 lbs. The expansion of steel by heat is, on an average, somewhat less than that of wrought iron, and varies as the steel is hardened or tempered. The linear dilatation, between 32° and 212°F., was in Smeaton's experiments, 1-816th for tempered, and 1-870th for untempered steel; in the experiments of Lavoisier and Laplace the dilatations were 1-807th and 1-927th respectively; Troughton's experiments gave 1-840th, the condition of the steel is not stated. The soft steel used for construction differs very little in this respect from wrought

iron, and the same co-efficient of expansion may be used for it without risk of sensible error (Paragraph 310). The presence of a small quantity of manganese renders steel tougher and easier to work, but is not essential to good steel. The addition of ·05 per cent. of silicon to melted steel prevents bubbling. The effects of impurities are the same as stated for wrought iron. The presence of carbon is essential to steel, iron containing more than ·25 per cent. of carbon is steely; when the proportion is between this and ·5 per cent., the material is termed *steely iron, semi-steel, homogeneous metal,* &c., according to the mode of production; the mechanical properties of these compounds being intermediate between those of wrought iron and steel. When the proportion of carbon is between ·5 per cent. and 1·5 per cent., the compound is termed steel, but by some authors compounds containing less than 2 per cent. of carbon are classed as steel. Toughened cast iron being made by the addition of 1-7th by weight of scrap iron to molten cast iron, it contains 1·75 per cent. of carbon, and as steel containing 1·75 per cent. of carbon cannot be welded, it appears reasonable to apply the term steel to compounds containing less than 1·75 per cent.; between this and 1·9 to 2 per cent. the term toughened cast-iron is applied, and when the proportion of carbon reaches 1·9 or 2 per cent., the compound is termed cast iron. The larger the proportion of carbon in steel, the greater the difficulty and uncertainty of welding it, its liability to burn or be injured by heating, and the lower the temperature at which it runs. The material employed for engineering works is soft steel or steely iron containing a little carbon; for heavy tools, shear steel containing a medium proportion of carbon, and for fine cutting tools, cast steel containing 1 to 1·5 per cent. are used. Mr. Kirkaldy found steel fractured by a tensile load applied gradually presented a silky fibrous appearance; when fractured suddenly he found the fractured surfaces invariably appeared granular, as described for wrought iron (Paragraph 317); in the former case the surfaces of fracture diverged more or less from an angle of 90° with the axis of the bar, in the latter the section of fracture was always at right angles to the axis. The granular fracture of steel differs from that of wrought iron in being almost free from lustre, instead of presenting a brilliant crystalline appearance; the difference is well shewn when an iron bar with a steel skin is fractured. Hardening, by rendering the steel brittle, favours sudden failure, and consequently production of the granular fracture. As with iron, it is necessary in considering the strength of steel to consider its toughness as well as its tenacity; very hard steel is very tenacious, but being brittle it is unsuited to resist shocks. Very hard steel is suited for some purposes,

whereas the extremely soft is suitable for others; the hard brittle material used for metal-working tools is of a nature unsuited to engineering works, the material of which should be fitted to resist shocks and to give notice of impending fracture by exhibiting strain or taking a set. The tenacity of steel varies with its degree of hardness, mode of production, and manner and degree of working; the most extreme limits are 22·3 and 68·26 tons per square inch; the former is given by M. Prud'homme for cast steel, the latter by Mr. Wilmot for Bessemer bar. The extremes stated by Sir W. Fairbairn are 27 and about 60 tons, those given by M. Prud'homme are 63·5 and 22·3, but these authors agree in stating the average as 48 tons per square inch. In practice bars vary between about 44 and 58 tons per square inch, plates average 33 to 35. The steel used for construction is not a highly converted steel; it generally contains less than ·5 per cent. of carbon; it has not a high tenacity, and is not used hard. For mild steel plates the tenacity should not in practice be considered higher than 33 to 35 tons per square inch, but for more highly converted steel in bars 48 tons is a fair average. The tenacity of puddled bars varies between about 28 and 42 tons; that of plates between 37 and 45·8 tons; that of blister bar is stated at 46·5 tons, and shear bar at 52 tons per square inch (Kirkaldy). Cast steel bars vary in tenacity from 22·3 to 46 tons per square inch; the hardening was found to raise the tenacity from 38 to 46 tons (Kirkaldy). Homogeneous metal rolled bars vary in tenacity from about 40·5 to about 41·5 tons; forged bars have a tenacity of about 40·5 tons, and plates 32 to 43 tons. Bessemer steel ingot has a tenacity of about 28 tons, the hammered or rolled bar reaches 68 tons, rolled and forged its tenacity is about 50 tons per square inch, and the minimum tenacity of plates of mild steel is about 33 tons. The tenacity of steel wire may vary from that of the soft bar to that of steel piano-forte wire (100 to 120 tons per square inch); the tenacity of homogeneous metal wire may be considered somewhat more than twice that of soft iron wire. A tenacity of 53 to 54 tons per square inch of sectional area may be specified for small-sized homogeneous wire as used for cables—*e.g.*, the homogeneous wire in the French Atlantic cable, diameter ·1″, has a tenacity of 950 lbs., a load equivalent in intensity to 54 tons per square inch; the tenacity of the homogeneous wire for the Great Western cable, diameter ·095, was specified 850 lbs., equivalent to 53·5 tons per square inch. Steel rolled from the ingot is better than that made from bars piled together, and the Bessemer process produces a uniform material suited to engineering purposes but slightly more costly

than iron, removing one of the principal objections to the employment of steel, absence of uniformity in quality; as steel does not weld so easily as iron, its strength depends more on the mode of its manufacture. There is a slight difference between the longitudinal and transverse tenacities in plates and bars; in homogeneous metal and cast steel this difference is very slight and not of practical importance, in puddled steel the difference is greater. It depends on the manner in which the bars are piled, and in plates may reach 17 per cent. The ultimate extension of steel is very variable, in mild soft qualities it may be 20 per cent. or even higher; in mild Bessemer steel suitable for engineering purposes it is about 8·5 per cent., in cast steel plates it may not exceed 3 per cent., and in puddled plates it may be as low as 1·3 per cent. and as high as 12·5 per cent. The highest quality homogeneous metal in plates may stretch 14 per cent. before rupture, but the proportion is usually much less. As wire the ultimate elongation is about equal to that of ordinary iron wire; 18 per cent. may be specified if short lengths are tested. Homogeneous wire bears the torsion test for ductility better than ordinary iron wire, and it bears this test better than the elongation test (Cully). The resistance of steel to crushing varying with its quality and degree of hardness, no useful constant can be given—88 and 175 tons per square inch are stated as extremes; Sir W. Fairbairn's experiments, the specimens being of small size, gave 100 tons. The transverse strength of steel in pounds weight on a bar of one inch square section and one foot span was found by Sir W. Fairbairn to vary between 3333 and 6333 lbs.; Mr. Kirkaldy gives 6403 lbs. as the constant for hammered steel. The modulus of elasticity in Sir W. Fairbairn's experiments varied between 22,000,000 and 34,000,000, and was on an average 31,000,000. The following are from Professor Rankine's *Civil Engineering*:—

	Tenacity.	Modulus of Elasticity.
Soft steel,	90,000	29,000,000
Hard „	132,000	42,000,000

The modulus of annealed steel wire, specific gravity 7·622, was found to be 24,575,000 at ordinary temperatures, at 212° F. this was raised to 30,285,000; the modulus of annealed cast steel, specific gravity 7·719, was at ordinary temperatures 27,822,000, at 212° F. it was 26,044,000. The proof strength of steel is about one-third its ultimate strength, this is the proportion assumed in practice; it is sometimes stated as nearly one-half, but one-third is generally used, and should be adhered to in the present state

of knowledge of the subject. From the modulus of elasticity and proof strength may be calculated the modulus of resilience (Paragraph 57). The resistance to shearing is equal to about 80 per cent. of the tenacity (Kirkaldy).

339. The principles and practice of joining steel are the same as described for iron; Mr. Kirkaldy states the diameters of rivets should be proportionately greater than for iron. The means employed for the preservation of steel, and the advantages of employing it as compared with wood, are the same as described for wrought iron; steel is, however, more expensive but stronger than iron. As wire, the intensity of load on steel may be twice that admissible on wrought iron, and in engineering works generally mild steel may be loaded 50 per cent. in excess of wrought iron. Authorities agree in stating 8 to 10 tons per square inch as the maximum intensity of stress admissible in structures of steel plates; ordinarily 8 tons is the highest admissible, but as steel varies widely in strength 10 tons may be permitted when the plates are known to be above average quality. More care is necessary in punching steel than iron; steel plates may be reduced in strength 30 per cent. by punching as compared with drilling, but annealing restores the original strength. In substituting steel for iron economically it should be considered that if too thin, steel may rapidly be rendered unsafe by corrosion, or it may be liable to failure by buckling; in wrought iron extra thickness may be allowed to resist these sources of insecurity, in steel excess is less admissible by reason of the greater cost of the material. Steel has not hitherto superseded iron, by reason of a want of uniformity in the mechanical properties of steel plates and bars; but greater certainty has been attained in the manufacture of steel, particularly by the introduction of the Bessemer process, and being produced cheaply and of uniform quality it is superseding iron, particularly for structures where lightness has to be combined with strength. Steel is slightly more liable to corrosion than wrought iron, the relative oxidations in moist air are stated to be—

Cast iron, . . .	·42
Wrought iron, . . .	·54
Steel, ...	·56

340. For the blades of heavy tools when thin, as in spades, phaoras, &c., shear steel is the best material; it is easier to weld than cast steel, and is very durable; it may be used for axeheads, and is generally applicable to thin wood-cutting tools. Pickaxes, crowbars, jumpers, and other tools acting by their weight and required to have durable points or edges, are made

of iron steeled at the end—the steel should be renewed from time to time as it is worn away. Files were formerly made of blister steel, but as a vast number are worn out old files are re-melted, and files are therefore as a rule made of cast steel. The finer kinds of cutting tools, as chisels, plane-irons, drills, &c., are made of cast steel and iron welded together; the edge or blade being of steel, and the haft, bolster, or greater part of the blade of iron. For tools required to be used hard a highly converted steel is necessarily employed, but as mild a steel as practicable should be used, as easier to forge and weld; the more highly converted the steel the more liable it is to burn, and the greater the difficulty and uncertainty of welding it. Shear steel suffers less by heating than cast steel, and it is much more readily welded both to steel and iron. Iron and steel are welded together in the following manner:—The iron is placed in the hottest part of the fire, the steel is only heated just sufficiently, prolonged exposure to the fire being avoided; when both are heated to the required degree they are slightly dipped in borax or sand, as a flux, and hammered together. When cast steel is to be welded the steel is not so highly heated in the fire, it is brought up to the welding heat by contact with the hotter iron and hammering; experience and considerable skill are necessary to ensure soundness in the joint without burning the steel. As a rule tools should be used as soft as practicable, and as a general rule axes, mortise chisels, and many other tools liable to be unskilfully used should be softened before use, being frequently too hard as obtained in the market; if the edge of a tool be turned it may be more readily repaired than if chipped. For the angles of cutting edges, sharpening, and other particulars of tools, see Chapter IV. section 2.

341. Steel is used in preference to iron for hooks for cranes, and for insulator hooks for suspending line wires; it is commonly used for spindles when lightness and durability are required to be combined; it is used for spindles in the best pulley blocks, and might with advantage be used for the bolts and plates forming the shells, and for the hooks of light blocks used for straining line wires, lightness being of great importance. It is the best material for the spindles of crane and crab barrels. Sometimes spindles are case-hardened to give them a hard surface to resist abrasion, but case-hardened iron is inferior in tenacity to ordinary wrought iron. Steel is not applied to oval linked chains, being difficult to weld, but it is applicable to flat linked or long linked chains generally, and may be used with advantage for the connecting pins in iron ties. The advantages of steel as compared with iron are:—The greater degree of hard-

ness which can be given to its surface, fitting it to resist wear as spindles, pins, and similar bodies; and its lightness fitting it for use where portability or reduction of internal load are of importance; the cost of steel is, however, much greater than that of iron, and this is the principal obstacle to its more general employment.

342. Steel is not in use for the construction of telegraphs, excepting as line wire for long spans; telegraph posts might be made of steel plate when required of large size or exceptionally strong, but in ordinary posts it cannot be employed economically, for plate iron is already used as thin as admissible, and if steel were substituted it could not be used thinner than the iron. Mild steel, as homogeneous metal and homogeneous Bessemer metal, are used for line wire in towns, and for exceptionally long spans; for towns it is convenient, as thin light wire is required, and steel wire may be used much thinner than iron wire; for long spans steel wire may be employed with advantage, its modulus of tenacity being so much greater than that of iron wire. In all cases a soft steel should be used to avoid brittleness, therefore homogeneous metal is used whenever admissible in preference to steel proper—the use of the latter is exceptional. For town lines, when the object of employing steel wire is to diminish the weight of the wire, mild steel may be employed more economically than when the object of its employment is simply to increase the spans without reducing the conductivity, because in the former case the weight of steel used is less than that of iron. Whenever practicable when steel wire is used, it should be used of smaller size than iron wire applied to the same purpose, the object being to reduce the difference in cost—*e. g.*, for iron line wires No. 8 may be regarded as the average size, in steel No. 10 is more commonly used.

SECTION II.—*Copper, Zinc, Lead, Tin, and Alloys.*

343. Copper is corroded by unctuous bodies, dilute acids, and prolonged exposure to moist air; it oxidises if heated to redness in contact with air, the scales of oxide fall off and expose fresh surfaces of metal to oxidation, so that the metal wastes sensibly if the operation be repeated. When exposed a film of carbonate forms on its surface, and unless this be removed by a mechanical operation or the action of an acid, it serves as a protection to the metal beneath and prevents further corrosion. Nitric acid dissolves copper rapidly, but muriatic acid, strong or dilute, dissolves it only with access of air. Strong alkaline solutions do not act upon it as they do not contain air, but weak solutions,

particularly of ammonia, with access of air rapidly dissolve it. It is not corroded by dry air. The texture of very soft copper is crystalline, that of hard copper fibrous, lightish-red and silky. The density of copper varies between 8·6 and 9, when melted it is supposed to absorb oxygen and thus become porous. Its specific gravity when cast under common salt is 8·921, if melted in contact with the air without such precaution its specific gravity is 8·6 to 8·78; it may be increased to 9 by hammering. The specific gravity of cast copper in practice is commonly 8·6, a cubic foot weighs therefore 537 lbs. The specific gravity of sheet copper averages 8·8, its heaviness 549 lbs. per cubic foot; when hammered the averages are 8·9 and 556 lbs. respectively. The specific gravity of copper wire is about 8·899, and its heaviness 555·5 lbs. per cubic foot. The melting point of copper is commonly considered near 2000° F.: a low estimate, that of Daniel, is 1995°; a high one, that of Guyton Morveau, is 2204° F. Its strength is reduced by one-third at 600° F., and by one-half at a dull red heat. It expands $\frac{1}{580}$ of its linear dimensions by elevation of temperature from 32° to 212° F. If heated carefully to a low red heat, copper bars may be worked by the smith in the same manner as iron. When rolled drawn or hammered, it is rendered brittle, and requires to have its ductility or malleability restored by annealing. The effect of heating and sudden cooling on copper is the reverse of that on iron and steel, copper being softened by this treatment. The tenacity of cast copper may be as low as 7·5 tons per square inch, and as high as 11·5, it is on an average about 8·5. The tenacity of sheet copper averages about 13·4 tons per square inch, that of wrought bolts and bars 14·75 to 16 tons according to quality, the higher tenacity being that of the purest and most carefully worked. The tenacity of the best wire is stated as high as 27 tons, but it varies widely in practice according to the degree of hardness, and in hard wire according to size; if very soft the tenacity does not exceed that of bolts, in practice it is commonly stated at 17 tons per square inch; this estimate is that applicable to copper wire as usually employed. The tenacity of the purest copper wire as used for cable core varies from little over 15 to 17·5 tons. The following rule is applicable to this wire:—the strength of a wire or strand is 1½ lb. per pound weight per knot—*i. e.*, a strand weighing 200 lbs. per knot would carry 300 lbs. The modulus of elasticity of copper wire, tenacity 27 tons per square inch, is 17,000,000 (Rankine); the modulus of soft copper at ordinary temperatures is 14,960,000, at 212° F. 13,971,000, and for unannealed copper 17,000,000. Copper as used for cable core stretches 10 to 15 per cent. before breaking; it stretches 1

per cent. with two-thirds, and should not stretch sensibly with five-eighths of its ultimate load. The addition of 2 to 4 per cent. of phosphorus to copper increases its tenacity and hardness, but also its liability to corrosion. Copper stranded wire in cables is usually designated by the weight per knot. Copper sheet may be riveted as iron and soldered. Copper bits are commonly used as soldering tools, the advantages of using iron not having been recognised, but copper should only be used for small work. Copper in cables and thin wire in delicate apparatus, when practicable should be soldered with silver, as the metal is readily attacked or gnawed by the solder. Cast copper is liable to be porous, and hence phosphorus or 2 per cent. of zinc is advantageously introduced to increase its hardness and density. Copper is very useful for fastening timber under water; and in sheet, copper and several of its alloys are useful for covering the heels of masts and woodwork generally to protect its surface against insects and mechanical violence. For electrical purposes the purest copper procurable is used; it is usually tested for electrical conductivity, and a conductivity 90 per cent. of that of pure copper may be insisted on; for mechanical purposes copper alloys are generally employed, particularly those with zinc (brass). The wire used for electrical connections is used soft, and is usually joined with a twisted joint soldered or not according to requirements. Single wire covered with gutta-percha or India-rubber is not joined by the twisted joint in fine work, but by a scarf or lap joint bound with fine wire. Stranded wire is used for cable conductors because less liable to be broken by bending and more flexible. Stranded wires are joined by a scarf or splice joint (Paragraph 447). The following rules are useful:—The weight per knot of copper wire of diameter d in thousandths of an inch is for a single wire $\frac{d^2}{55}$, and for a stranded conductor about $\frac{d^2}{70{\cdot}4}$; the weight of a wire per statute mile is $\frac{d^2}{63}$ lbs. Copper wire is not used alone for overhead wires; in America a compound wire is used consisting of a core drawn from cast steel, this is tinned covered with a ribbon of copper put on helically, the compound wire is then passed through a bath of molten tin to cause adhesion between the copper ribbon and the core. The inventor claims for this compound wire as compared with iron wire in general use, greater durability, particularly near the sea, and greater tensile strength with a given electrical resistance and weight. A sample containing 120 lbs. of steel and 80 lbs. of copper per statute mile, had an ultimate

tenacity of 1051 lbs. and an electrical resistance of 9·38 ohms. This wire is not in use in Europe, but some thousands of miles of it are in use in America; it is more than twice as costly as iron wire, but it may be economical where transport is very expensive, and the number of poles per mile can be reduced by its use.

344. The specific gravity of ZINC or SPELTER varies between 6·8 and 7·2, and its heaviness between 424 and 449 lbs. per cubic foot. When cold it is brittle; it has its greatest malleability and ductility at 212° to 220° F., and the discovery of this fact has led to its extensive employment as sheet. It is heated by immersion in boiling solution of salt and rolled hot. It melts at about 700° F., and readily burns, if heated in contact with the air. Its tenacity varies between 3 and 3·6 tons per square inch. Zinc is more readily attacked by acids when impure; zinc of commerce is always impure. Pure zinc requires eight days for its solution in dilute acid which would dissolve the same quantity of commercial zinc in an hour. Zinc oxidises superficially on exposure to the atmosphere, but the oxide protects the metal beneath it unless acids be present to remove it.

345. TIN melts at 426° F.; it resists oxidation better than any other metal used in engineering. It is used for covering iron and copper to protect them, and to form alloys. Most of its alloys are harder than the constituent metals.

346. LEAD is used for covering roofs, for fixing iron into masonry, and for alloying with other metals. It melts at about 630° F. Its specific gravity is 11·4, its heaviness 712 lbs. per cubic foot. When rolled its tenacity is 1·4 to 1·5 ton per square inch.

347. The alloys in general use are BRONZE or GUN-METAL, alloys of copper and tin; BRASS, alloys of copper and zinc; and *soldering alloys*, composed of mixtures of tin, lead, zinc, copper, gold, and silver, according to the purposes for which required. To these alloys may be added ALUMINIUM BRONZE, an alloy of copper and aluminium. The maximum degree of homogeneity is attained in an alloy when the constituent metals are mixed in proportions ruled by their chemical equivalents, but such proportions are frequently departed from. The principal alloys of copper in common use are the following:—

	Copper.	Zinc.	Tin.
Brass for sheet, ...	84·7	15·3	...
Mosaic gold, and good yellow brass for turning and filing,	66	33	...
Another good brass, . . .	80	20	...
Gun-metal for bearings, &c., .	90·3	9·67	0·03
Muntz's metal, ...	60	40	...

Brass for rolling and drawing is best composed as above, but for turning 2 per cent. of lead renders it easier to work. The bronze in use for cannon consists of 90 to 90·5 per cent. of copper, the remainder being tin; a similar alloy is used sometimes for other purposes. More exact proportions than those given above are the following:—Bronze (or gun-metal), 1 equivalent of tin to 16 of copper; brass, 1 equivalent of tin to 2 or 4 of copper; aluminium bronze contains only 5 to 10 per cent. of aluminium. The tenacity of bronze used for cannon averages between 14 and 15 tons per square inch (Anderson). The tenacity of Muntz's metal is about 22 tons; the tenacity of brass varies with its composition and the extent to which worked. Brass wire has a tenacity of 22 tons, its modulus of elasticity is 14,230,000; the tenacity of cast brass is but little more than one-third that of wire. The addition of phosphorus to brass in fusion causes it to become very fluid, and renders it easier to obtain sharp and sound castings. The specific gravity of cast brass varies between 7·8 and 8·4, and its heaviness between 487 and 524·4 lbs. per cubic foot; the specific gravity of worked brass exceeds 8·5. The modulus of elasticity of annealed brass, specific gravity 8·247, is 12,807,900. For the composition and properties of alloys used for soldering, and the principles and practice of their application, see Chapter IV., section 3.

CHAPTER III.

INSULATING MATERIALS PROPER.

SECTION I.—*Gutta-percha.*

348. GUTTA-PERCHA is the concrete juice of the *Isonandra gutta* or *Is. percha*, a large tree of the Sapodilla order, called also the Taban tree. It rises to a height of 60 or 70 feet, the trunk being 3 or 4 feet in diameter; it grows in alluvial soils at the foot of hills in certain parts of the Malayan Archipelago, Southern Asia, and Dutch Guiana. The chief supply was obtained from Singapore; the words *gutta percha* are Malayan, the former signifies gum or concrete juice of a plant, the latter the special tree. The juice was obtained by felling the tree and cutting rings through the bark a foot or eighteen inches apart, the milky juice was received in suitable vessels and inspissated by boiling; the wasteful practice of felling the trees threatened seriously the

source of supply, when the matter was taken up by an English company, who introduced the practice of obtaining this juice as caoutchouc is procured, and this practice is now followed (Section 2). It arrives in Europe in blocks of several pounds weight, and contains sawdust, earth, and other impurities sometimes introduced as adulterants.

349. The best gutta-percha is yellowish and fibrous, other kinds are reddish or white, and frequently sticky; there exist varieties between caoutchouc and gutta-percha, and these two substances are sometimes mixed; the manufacturer mixes the several kinds of gutta-percha together. The blocks of impure material are cut into thin slices by knives attached to a wheel revolving 300 times a minute, these slices are softened in hot water, and further reduced by being torn by jagged teeth; the mass is then purified as much as possible by washing in hot and cold water. It is then masticated—that is, kneaded into a paste in a machine having grooved rollers, kept hot by steam or hot water; the pasty mass is then strained through fine wire gauze, again masticated, dried, and ultimately rolled into thick sheets or other suitable form, or applied directly to the purpose for which it is required.

350. Gutta-percha is composed of carbon and hydrogen, the results obtained by different analysts vary considerably; it is composed proximately of three isometric constituents, whose composition is C^8H^{14}, these are:—*pure gutta*, a substance insoluble in alcohol cold or boiling, *alban*, a crystalline substance insoluble in cold but soluble in boiling alcohol, and *fluavil*, a yellow resinous substance insoluble in cold alcohol; the proportions of these constituents are—

Pure gutta, ...	75 to 82 per cent.
Alban, ...	14 to 19 ,,
Fluavil, ...	4 to 6 ,,

In general products of oxidation are present. Gutta-percha varies much in quality and composition, and the gutta-percha of industry is not the pure material of the laboratory, hence the differences between the results of different analyses. Dr. Maclagan's analysis gave 86·36 carbon and 12·15 hydrogen; Blavier states the composition to be 88·96 carbon and 10·04 hydrogen; both of these differ considerably from that given above. When exposed to the air, particularly at temperatures between 77° and 86° F., it oxidises and becomes brittle, losing its flexibility, tenacity, and extensibility, and it shrinks and cracks so that wires covered with it become exposed at intervals; its colour when oxidised is very dark brown or almost black, and it

resembles pine resin in mechanical properties. Exposure to the sun's light greatly facilitates oxidation, and the change is most rapid in thin masses. Gutta-percha protected by leaden tubing has been found perfectly preserved after some years in India, not being even darkened in colour, unprotected wire would have become unserviceable after a few months exposure; in France lead coated gutta-percha covered wire is used, the gutta-percha is not found visibly deteriorated in upwards of twenty years. In the climate of England gutta-percha in thick masses may be kept safely for long periods, provided it be preserved from light, be kept moderately cool, and the surrounding air be not frequently changed; thickly covered underground wires are found serviceable after fifteen or more years of use, although somewhat oxidised superficially; such wires are usually covered with a serving of tape soaked in Stockholm tar, which greatly hinders oxidation. Even in temperate climates *thin* masses are better preserved under water until required for use, but if thinly coated wires be kept from the sun's light, as when forming office connections in cupboards and under floors, the coating lasts many years. In tropical countries gutta-percha deteriorates rapidly, a few months' exposure indoors is sufficient to render it unserviceable; it cannot, therefore, be used except for temporary purposes. Gutta-percha covered wires laid in cement were tried in France, and ten years after they were laid down the gutta-percha remained perfectly good. Gutta-percha deteriorates rapidly in soil impregnated with illuminating gas, kept under water it does not oxidise. It is stated gutta-percha does not oxidise if kept from the light (Wurtz's *Dict. de Chem.*), but upon one occasion in the East Indies several large drums of covered wire were found upon examination to be completely oxidised although they had not been unpacked; light could not have penetrated, but the cases were sufficiently damaged by rough usage to admit air; warm air is evidently sufficient to cause oxidation without access of light. Gutta-percha is insoluble in water, sparingly soluble in anhydrous alcohol and anhydrous ether (Paragraph 350), dissolves in small proportions in boiling olive oil, but is deposited on cooling, is freely dissolved by the following solvents aided by heat: Sulphide of carbon, mineral naphtha, coal tar naphtha, benzine, chloroform, and oil of turpentine. Gutta-percha is carbonised by strong sulphuric acid, and converted into a yellow resin by nitric acid; it is not altered by ferments; in the neighbourhood of oak trees it has been found entirely changed by a fungus (*Journal S.T.E.*, Vol. II.) Gutta-percha covered wire is usually served with tape soaked in Stockholm tar sometimes sanded; wood tar is not injurious, coal tar is unless purified, and gas tar is always prejudicial. Stock-

holm tar is a preservative, but impairs the insulating property. By dry distillation gutta-percha yields very inflammable oils. The solutions in chloroform and sulphide of carbon may be almost deprived of colour by filtration, and by cautious evaporation a colourless and remarkably porous mass is obtained which may be melted, and has all the properties of ordinary gutta-percha.

351. At about 115° F. gutta-percha softens and becomes pasty although still retaining much of its tenacity; between 100° and 144° F., it may be readily spread into sheets or drawn into threads or tubes; at 120° it is plastic, and if core be exposed to 130° or even less the wire becomes eccentric; near 212° F. it melts, suffering a pasty fusion; it becomes fluid at about 266° F., warmed further it boils and inflammable oils are distilled off. When altered by oxidation it melts at a lower temperature, and if completely oxidised it becomes fluid at 212° F. Heat increases its electrical conductivity, at about 72° F. it offers but half its resistance at 32° F. Its suppleness and ductility diminish as its temperature is lowered, but not to the same extent as in caoutchouc; it retains its flexibility at 14° F.

352. The density of purified gutta-percha is said to vary between ·9693 and ·981, and its heaviness therefore between 60·56 and 61·32 lbs. per cubic foot; but when the air is expelled from its pores by immersion in water it sinks.

353. At ordinary temperatures drawn gutta-percha has an ultimate tenacity of about 3500 lbs. per square inch. Willoughby Smith's improved gutta-percha, being gutta-percha prepared in a particular manner and of the same specific gravity as ordinary gutta-percha, is stated (probably on the authority of the manufacturer) to have a mechanical strength (tenacity is apparently referred to) 12 per cent. greater than that of ordinary gutta-percha. One writer has attributed to gutta-percha a tenacity about equal to that of strong leather, but this is upwards of 4000 lbs. per square inch, and is too high. Only a small portion of the ultimate strength of the material can be rendered available, as it stretches 50 to 60 per cent. before breaking. Stretching or drawing increases its tenacity, but only in the direction drawn, the transverse tenacity remains comparatively weak; if it be stretched to twice its original length it is stated (Wurtz's *Dict. de Chem.* Art. G.P.) that it will support longitudinally the action of a force twice that which was required to stretch it. Permanent set commences at ordinary temperatures, in unstretched gutta-percha, at about 672 lbs. the square inch (Clark & Sabine); stretched or drawn as used in cables, it will resist a strain of about 1000 lbs. the square inch; Blavier found it resisted 994 lbs., it elongated 4 per cent., but regained its

orginal length when the load was removed. Professor Fleeming Jenkin states the available strength of gutta-percha in cable cores at about one-third the ultimate strength, or about 1160 lbs. per square inch.

354. The manufacture of gutta-percha and its application to the purposes of telegraphy, cannot be carried on wholly by machinery with that automatic accuracy often attained by machinery in working in metals and wood. Notwithstanding the improvements in manufacture and working which have been effected, the work of the machine requires constant supervision and frequent repair. Gutta-percha is applied to wires in separate layers in order that a fault in one layer may be covered by the next; as many as twenty layers *have* been used, but for ordinary wires five layers are employed, for the small sizes fewer. The principle of the covering machine is shewn in fig. 64: the warm gutta-percha is placed in a strong cylinder A, the wire 1 2 passes through the cylinder as shewn, being drawn through at an equable rate; the pressure on the piston B causes the gutta-percha to emerge at 1, covering the wire to the thickness required for one layer; the operation is repeated as many times as coatings required, the gauge of the drawplate, &c., being suitably modified. The gutta-percha in the cylinder is kept warm, and after emerging on the wire it is cooled before being coiled. Gutta-percha covered wires covered with simple gutta-percha put on in the manner described above, were found liable to injury by reason of the absence of adhesion between the wire and coating; if the core were stretched it elongated, but in contracting when the load was removed the coating contracted more than the wire; the wire was thus bent, and the coating being loose the wire was forced nearly or quite through the gutta-percha, thus injuring the insulation. The liability to this class of accident is now removed by coating the wire with an adhesive mixture (Chatterton's compound) consisting of one part Stockholm tar, one part resin, and three parts gutta-percha, and this is used between the layers of gutta-percha; the wire and its covering and the several layers are thus strongly bound together, and act as a single solid. The specific gravity of Chatterton's compound is about the same as

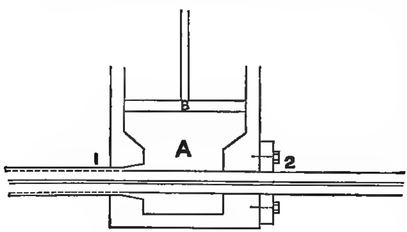


Fig. 64.

that of gutta-percha, but its electrical resistance is less; hence it should be thinly spread. Gutta-percha is also used in thin sheets, these are rolled from the warm material, or very thin leaves are obtained by evaporating solutions. Gutta-percha may be readily joined when warmed, but if melted it remains sticky and the joint is spoiled. Great care is essential to success in joining gutta-percha covered wire, many joints which appear perfect when made rapidly deteriorate; the joints in underground lines and cables are justly regarded as the weak points in the system. The source of heat should be clean, a spirit lamp is that generally used for warming gutta-percha and gutta-percha irons; sometimes a spirit lamp in an iron chimney (a lamp furnace), and sometimes a charcoal fire is used—the last is used for heating irons only. As great care must be taken to avoid over-heating, a fusible solder is commonly used for joining the copper wire. The tools required are scissors—preferably curved—and smoothing irons, and a pair of clips fitted to a stand for holding the core are sometimes used; the materials necessary are sheet gutta-percha, a stick of Chatterton's compound, and naphtha. The principal precautions to be observed to ensure perfect and permanent adhesion and a safe joint are the following:—

PERFECT CLEANLINESS in dealing with the gutta-percha, the wire to be covered must be clean; this is usually ensured by washing it with naphtha after soldering, water is sometimes used, and sometimes in inferior work this precaution is neglected. The dirty part of the work is best done by an assistant. The hands and tools used to touch the joint should be very clean; greasy matter in the smallest quantity prevents adhesion, even the grease in the perspiration from the hand of the operator is sometimes sufficient. Before kneading the gutta-percha with the fingers the hands should be washed, naphtha is preferable to water for this purpose, as it diminishes the secretion of perspiration and hardens the skin somewhat. As the fingers and scissors are always wetted to prevent them sticking to the softened gutta-percha, the last should be carefully dried before applying the Chatterton's compound or a fresh surface of gutta-percha.

Care should be taken to express from the joint as it is made any air enclosed, and thus make the joint solid.

The joint should be made at the LOWEST TEMPERATURE *consistent with perfect adhesion* between the several layers of which it is composed, a sufficient length of conductor should be bared to prevent the risk of over-heating the gutta-percha when soldering, and for the same reason the soldering bolt used should not

be larger than necessary for the work. The best length of joint is on an average 5 to 6 inches, it is sometimes only 4, but this must depend on the size of the conductor; the length should be as short as consistent with security against over-heating when soldering. If any part of the work be accidentally burned it should be cut out and the joint re-commenced. Care should be taken that the conductor is not allowed to become eccentric during the application of heat.

Gutta-percha varies in quality, and the properties of the older material may be altered by oxidation. Dissimilar qualities do not always readily adhere; hence, the quality of the material should be either the same throughout, or the sheet material should be selected with reference to its property of combining with the material of the core; the use of Chatterton's compound probably renders difference of quality less important, but it cannot be neglected without risk of failure.

The principal *mechanical* conditions to be observed are:—care should be taken in joining the conductor to finish the joint without projecting ends, in twisted joints this is particularly dangerous; the ends should be turned down carefully, and some authorities recommend the spare ends be broken off with the pliers rather than cut off, to avoid points (see Paragraph 447). A sufficient length of sheeting should be left at each end of the joint to finish off well. The joint in the conductor should be in the middle of that in the covering, and they should be concentric. Care should be taken in baring the conductor not to damage it with the knife or other instrument used to cut off the gutta-percha. In kneading warm gutta-percha with the fingers, or cutting warmed sheet, the fingers or scissors should be damped to prevent adhesion; but cold gutta-percha sheet may be cut with dry scissors.

Joints are made in different ways, and—according to the degree of perfection necessary—more or less care and labour are bestowed on them, from the simplest scarf joint made for a temporary purpose, in which neither Chatterton's compound sheet gutta-percha nor naphtha is employed, to the joint in a cable core in the making of which the utmost attainable perfection is desired. The simplest form of joint is a scarf, fig. 65, or a kind of butt joint made without the addition of other material than that of the core joined. The scarf is made as follows:—The coating and conductor of each end to be joined are cut through at right angles to their axis level with each other, the core is then warmed gently, and the gutta-percha is drawn back from the wire with

Fig. 65.

the damp fingers to expose a sufficient length of the conductor at each end for the joint in the conductor; this joint having been made, the gutta-percha drawn back on one side is gradually warmed, kneaded, and spread over the whole length of the joint; it is pressed close to the conductor, made to taper, and the superfluous material separated. The surface of the joint having been dried, the other knob of gutta-percha is worked in the same manner over the whole length of the joint, and the superfluous material is removed. A simple butt joint is made by proceeding as in the scarf joint as far as the joint in the conductor, then instead of kneading the gutta-percha from each end over the whole length of the joint, the knobs of material are kneaded down to meet in the centre of the joint; they are here kneaded together to produce as intimate a union as possible, and the superfluous material is removed. These joints may be smoothed by rubbing with the wet hand to improve their appearance, they are the least secure kind of joint, and are unsuited to important purposes. The scarf joint described above may be made much more secure in the following manner:—After joining the conductor wash the conductor and ends of the core clean with naphtha, warm the conductor and a stick of Chatterton's compound, and apply a little of the latter to the conductor, spreading it evenly with the warm tooling-iron, work down one end of the gutta-percha, as described above, but before covering this layer with the material from the other side, apply a little Chatterton's compound to its surface by rolling a heated stick of compound along the joint in three or four places and spreading the adherent material evenly by tooling. The second knob of gutta-percha is now to be spread over the first, as already described. This joint only differs from the simple scarf joint, fig. 65, in the use of Chatterton's compound between the conductor and covering, and between the two layers of the latter, and in the use of naphtha to ensure chemically clean surfaces. The butt joint may be improved as follows:—Use naphtha to wash the conductor and gutta-percha, and put a thin coating of compound over the conductor, work the gutta-percha down first from one side then from the other to meet in the middle of the joint, knead well to cause intimate union, cut off the superfluous material, apply Chatterton's compound over the whole joint spreading it by tooling, wrap the joint in a ribbon of sheet gutta-percha laid on longitudinally, both joint and sheet being warmed, tool it to cause perfect adhesion working from the centre of the ribbon to exclude air, and closing its edges last with the warm tooling-iron. This joint is one of the most perfect used. The following modified scarf joint, in which sheet gutta-percha is used, is more

common; it is the highest form of joint, and is used for gutta-percha cable core of all kinds:—The gutta-percha is cut off the conductor with a knife for $1\frac{1}{2}$ inch to 2 inches at each of the ends to be joined, and the conductor is joined in the manner decided on (single wire is usually joined by the twisted joint) and soldered; the conductor and the gutta-percha, for 2 or 3 inches on each side, are carefully washed with naphtha. Chatterton's compound is applied to the conductor as described above; the gutta-percha is warmed for about 2 inches on one side of the joint, and kneaded down to cover the joint and meet the gutta-percha on the other side, but a small piece of material from each end is usually rejected as possibly dirty or damaged by heat; to this covering is applied a coating of Chatterton's compound evenly and thinly spread by tooling, and over this the gutta-percha from the other end is worked down, thus forming a scarfed joint usually 5 to 6 inches long. The material kneaded down from each side does not, as in the simple scarfed joint, extend the entire length of the joint, but it should in each case extend to an equal distance on each side of the conductor joint; it is evident also that at this stage the diameter of the joint is less than that of the core. Apply another layer of Chatterton's compound over the whole length of the joint, and place round the joint a ribbon of sheet gutta-percha arranged longitudinally, the ribbon and joint being both warmed, the ribbon is usually 4 to $4\frac{1}{2}$ inches long and wide enough to allow some spare to be cut off longitudinally with the scissors; the ribbon seam should not be closed at the edges until the air has been expressed from beneath it by working it from its centre, the seam is made above to be in sight, the sheet should be stretched before application, and the seam should overlap a little to ensure perfect contact. The joint is finished by applying another layer of Chatterton's compound, and rubbing the joint smooth with the wet hand. The sheet is best applied by fixing it at one end and stretching it on longitudinally, and perfect junction between the sheet and core at the ends of the joint should be produced by applying the heated iron. In this joint there are three layers of gutta-percha alternating with compound; if the core be covered with four layers of gutta-percha, and it be desired to imitate this in the joint, an additional layer of sheet material may be applied—the second seam in this case should be placed on the opposite side of the joint to the first seam, and generally if more than one seam be introduced the sheets should break joint round the core. A thin layer of Chatterton's compound and rubbing with the wet hand may be applied as a finish to any joint to improve its appearance. Several other products analogous to gutta-percha have been im-

ported, but they have not come into general use, although some of them possess useful properties; the reasons being they oxidise more rapidly than gutta-percha, and in some cases offer greatly inferior resistance to the passage of electricity. In the arts generally gutta-percha is seldom employed pure; it is mixed with caoutchouc to give it flexibility, with 10 to 30 per cent. of gum lac to give it rigidity; increased resistance to the oxidising action of light and air is given by an admixture of 5 to 10 per cent. of paraffin or suet, or by treating it with warm solution of caustic soda, about 12 ounces to the quart of water, the alkaline solution removes the alterable parts. If sulphur be combined with gutta-percha, as in vulcanising caoutchouc, the effect is somewhat the same—the gutta-percha is rendered less fusible and less prone to oxidation on exposure to air and light. The process of vulcanisation is almost the same as in the case of caoutchouc, but other matters in addition to the sulphur have to be added, as otherwise an essential oil appears to be disengaged which impairs the homogeneity of the product. Vulcanised gutta-percha, not being durable, has not come into use for general purposes. For telegraph purposes simple gutta-percha and the mixture termed Chatterton's compound are the only forms in which gutta-percha is in general use as an insulator; mixtures of different qualities are used. Several of the preparations mentioned above might be employed under some circumstances with advantage. Oxidised gutta-percha, probably mixed with other substances, as fresh gutta-percha, caoutchouc, &c., is used for small picture frames, mouldings, &c., old covered wire may therefore generally be sold advantageously when no longer of use as covered wire for telegraph purposes. Gutta-percha is the material most generally employed in Europe for insulating office connections and underground cables, the use of India-rubber being far less general; in India India-rubber is used for these purposes and for river cables. Gutta-percha is the material more generally used for insulating submarine cables. The relative merits of these two substances, as far as known, are treated of in Paragraph 363.

Section II.—*Caoutchouc.*

355. *Caoutchouc, India-rubber,* or *gum elastic,* is found in the milky juice of a great many tropical and some European plants, particularly those belonging to the fig, spurge, and dogbane orders. The *Siphonia cahuchu* or *caoutchouc,* a tree growing over a vast tract of country in Central America and in Java, yielded formerly the greater part of the good caoutchouc; the material was obtained by way of Para, this is still most highly esteemed

and is termed *Para* gum or caoutchouc. The *Urceola elastica* abounds in the islands of the Indian Archipelago, it produces the *gumtowan* of the Malays. The *Ficus elastica* is the source of a large supply, it extends over more than 10,000 square miles in Assam and other parts of the East Indies. The other trees which furnish caoutchouc are *Heva caoutchouc, H. guianensis, Jatropha elastica, Ficus Indica,* and *F. religiosa;* the supply is therefore more abundant and certain than that of gutta-percha. The sap of the tree is obtained from an incision through the bark; formerly this sap was spread on clay moulds to dry, and imported in the forms of bottles, balls, and crude lumps; a large quantity of the juice was also imported in bottles, but it is now generally imported solid, a much cheaper method. It varies in quality according to the species of tree; the juice from old trees drawn in the cold season is the best. The *Ficus elastica* of Assam, a large tree, may be tapped once a fortnight in the cold season, and will yield upwards of 40 lbs. of juice containing four to six parts water and six to four caoutchouc. The juice varies considerably in colour and composition according to the source from which derived; specimens imported in well-closed vessels had specific gravity 1·0175 to 1·04125 (Ure), the lighter kind yielded 37 per cent., the heavier and thicker 20 per cent. of caoutchouc, the source of supply was probably *Ficus elastica;* another specimen, probably from *Siphonia elastica,* was found to have specific gravity 1·012, and to contain 45 per cent of caoutchouc; but analyses differ widely, the juice being derived from different sources and prone to alteration. When the juice is heated its albumen coagulates and rises to the surface; it mixes with a small proportion of water and coagulates as when undiluted, but if the water added exceed a certain proportion it separates the caoutchouc, and the separation is the more rapid if the water contain salt; the caoutchouc rises to the surface. Alcohol produces the same effect.

356. Caoutchouc as imported is sometimes tinged brown by aloetic matter, and occasionally it contains tarry matter in its pores, the produce apparently of decomposition; it is necessary that aloetic matter be removed by boiling in water, as if permitted to remain it destroys the texture of the caoutchouc by its decomposition. The rough masses imported are masticated in water to remove impurities, and afterwards dried to reduce them to a homogeneous mass; this irregular mass is then shaped into regular masses, from which sheets, threads, &c., can be cut economically. The knife used to cut caoutchouc should be kept wetted. *Pure* caoutchouc is colourless and transparent, but that of commerce differs in colour, the best being a light yellow; under

the microscope it appears formed of tubes and to contain cavities, it may therefore be used as a dialyser. Caoutchouc is impaired by mastication, which breaks its fibrous structure, diminishes its elasticity, and increases its porosity. Immersed in water caoutchouc is absorbent, probably by reason of its porous structure; this absorption may reach 25 per cent. of the weight of the material after a month's immersion, when its volume may be augmented 15 per cent., and its colour rendered lighter. Manufactured caoutchouc covering wires absorbs water superficially only, and at ordinary pressures not in sufficient quantity to sensibly impair its insulating power. As the water on the outside evaporates, the caoutchouc contracts and hinders the evaporation of the water from the interior of the mass, this impairs its quality.

357. The specific gravity of caoutchouc varies between ·919 and ·942, it is not increased permanently by any degree of pressure.

358. By long boiling in water it swells and becomes somewhat sticky, more readily soluble in its proper menstrua, but when exposed to the air it soon resumes its original volume and consistence. When pure it is insipid and has little or no odour. It contains no oxygen. The following analyses give its composition:—

	1.	2.	3.	4.
	Faraday.	Ure.	G. Williams.	
Carbon, .	87·2	90·6	86·1	87·2
Hydrogen, .	12·8	10·0	12·3	12·8
Ash, . .	...	...	0·9	...
Azote and loss,	...	...	0·7	...
	100	100·6	100	100

Analysis No. 2 gives C^3H^2, but the agreement between the other three is so close that they are generally accepted. Assuming 87 and 13 as the percentages and 6 and 1 as the equivalents, the composition is represented by $C^{29}H^{26}$; the author (M. Ch. Laut) of the article C. in Wurtz's *Dict. de Chem.* represents the composition by C^4H^7; this however, would represent a percentage composition widely differing from the results of the analyses, viz:—carbon 77·42 and hydrogen 22·58 per cent. Other analysts state there are traces of sulphur and chlorine, and as proximate constituents fatty and colouring matters, and three compounds of azote. Caoutchouc is not acted upon by sulphurous, muriatic, or fluo-silicic acids. Strong sulphuric acid decom-

poses it slowly in the cold, but readily when aided by heat. Nitric acid decomposes it completely, so also does a mixture of nitric and sulphuric acids. It is not acted upon by dilute acids nor dissolved by the strongest alkaline solutions even when boiling. Exposure to the action of alkaline solutions generally hardens it, but contact with solution of soda (40° Baumé) for several hours renders it sticky. Chlorine attacks it with time, rendering it hard and brittle, and it is readily acted upon by nitrous acid. By some authors it is stated chlorine does not attack caoutchouc, but possibly with prolonged exposure many re-agents at present deemed indifferent would affect it more or less. Exposure to air and light causes gradual oxidation, the caoutchouc being transformed into a brilliant resin resembling gum lac; this change is more rapid in manufactured than crude material, and is favoured by alternate exposure to sun and humidity. When oxidised, caoutchouc is soluble in wood spirit, alcohol, chloroform, benzine, and alkaline solutions, but not in turpentine, sulphide of carbon, and ether. It yields water by distillation, proving the presence of oxygen; its percentage composition was found to be—carbon 64, hydrogen 8·46, oxygen 27·54. Oxidation is prevented if the caoutchouc be kept under water. In contact with copper, as in covered wires, caoutchouc becomes viscid and even fluid, it either separates from the copper or leaves the latter merely covered with a sticky covering; the change is not well understood, it is stated it does not take place under water if the caoutchouc be pure. To prevent the change copper wires to be covered with India-rubber should be carefully tinned, a practice generally adopted. Sulphur and several of its compounds act on caoutchouc in a remarkable manner described in Paragraph 360.

359. Caoutchouc is insoluble in alcohol, but it absorbs sometimes 20 per cent. of its bulk of warm anhydrous alcohol; on evaporation of the liquid it gradually regains its original properties, but is more translucent and less tenacious. It readily dissolves in ether deprived of alcohol by washing with water, the solution is colourless, and when recovered by evaporation the solid caoutchouc remains sticky for some time. Treated with naphtha from coal tar or petroleum, it swells to about thirty times its original bulk, and when triturated and worked through a sieve, it affords a homogeneous varnish used in waterproofing cloth. It dissolves in bisulphuret of carbon and some essential oils, as oils of lavender and turpentine. In the fixed oils, as linseed oil, with certain precautions, but the solutions do not dry well the residue remains sticky; the more volatile the solvent the less likely is the residue to be sticky, hence the most volatile

solvents are preferred. One of the most perfect solvents is 100 parts bisulphuret of carbon to 6 or 8 of anhydrous alcohol. The solution of caoutchouc for waterproofing is effected in close vessels by triturating machinery, the heat developed is sufficient to favour the process of solution, and as much as 13 cwts. of caoutchouc are dissolved at one time, three days being required to complete the solution; the varnish is used very thick, for fine work it should be strained. For very fine work ethereal solution is used as it leaves the caoutchouc free from disagreeable smell, the stickiness of this varnish is removed by dusting the surface of the work with sublimed sulphur or French chalk. To effect the solution in ether, the caoutchouc should be cut into shreds and boiled in water for two hours, the ether will then dissolve it in a few days. Thirty-two parts rectified oil of turpentine to one part caoutchouc forms a good flexible varnish; 15 to 20 grains of caoutchouc to 2 ounces of chloroform, half an ounce of mastic being added afterwards, and the whole macerated for a week, forms a good transparent cement—it is used cold with a brush. Caoutchouc is composed of two isometric compounds, one solid, elastic, and sparingly soluble, resisting almost all solvents; the other semi-fluid, adhesive, and readily dissolved; to this second is due the property of soldering by pressure, and to the existence of these two constituents is due the peculiar phenomena attending solution, which is generally incomplete. These components may be separated by using sufficient quantity of the solvent without agitation; their relative proportions vary with the nature of the solvent and quality of the caoutchouc—*e.g.*, anhydrous ether extracts 66 per cent. of white soluble matter from the amber-coloured gum, oil of turpentine extracts 49 per cent. of yellow soluble matter from the common material.

360. Caoutchouc is a bad conductor of heat. At ordinary temperatures it is soft, flexible, and highly elastic, its elastic flexibility being its characteristic property. Below 50° F. it hardens with decrease in temperature, at 32° F. it is hard and rigid, and resembles leather in appearance; if lowered in temperature, while stretched, it retains its altered dimensions, but it regains its elasticity and original dimensions if heated above 104° F., it also regains its properties under light traction, probably by reason of the heat developed. As its temperature is raised it becomes more flexible and soft; it is soft at 248° F. (one authority states it begins to melt at that temperature), about 293° F. it is sticky and adherent to hard bodies, at 338° F. to 356° F. it melts into a thick liquid like treacle, but its composition is unaltered. If fused it remains sticky and semi-fluid upon cooling, but if it has not been heated much above its melting point, on exposure

to the air in thin layers it recovers its original properties. If heated to 398° F. it begins to fume and is converted into a viscid mass, which does not dry; it forms a drying cement with half its weight of slaked lime and an equal quantity of red lead. If caoutchouc be distilled at 600° F. an exceedingly volatile liquid caoutchocine passes over; this fluid is speedily decomposed if exposed to the air, it is an excellent solvent of caoutchouc copal and other resins, it is used mixed with alcohol; at a lower temperature sulphuretted hydrogen, hydrochloric acid, carbonic acid, &c., are given off. The residue left in the retort after distillation with oil as a solvent, forms a varnish impervious to moisture and very elastic, it is used by shipwrights. Caoutchouc is very combustible, it burns with a white flame, and leaves no residue.

361. When caoutchouc is combined with sulphur it is said to be vulcanised; the proportion of contained sulphur may be as great as 20 per cent., but only 1 or 2 per cent. is actually combined with the caoutchouc as an essential, the surplus is mechanically mixed and may be gradually eliminated by alternate extension and contraction, covering the surface of the material with a fine powder, or it may be removed by treatment with alkaline solutions or solvents of sulphur. The presence of sulphur does not sensibly modify the composition of the caoutchouc; it is generally admitted that the sulphur combines with one of the two isometric compounds composing the caoutchouc (Paragraph 359)—viz., that one which is soluble, is hardened by a low and softened by a high temperature, is sticky, and to which ordinary India-rubber owes its property of joining when two freshly-cut surfaces are pressed together; the combination of sulphur with this constituent has the properties of the other constituent, hence the vulcanised caoutchouc has the properties of the latter exclusively. Vulcanised is distinguished from ordinary India-rubber in the following particulars:—*Firstly*, It does not become hard and rigid as ordinary caoutchouc at about 40° F., but retains its pliability and flexibility at low temperatures; *secondly*, freshly-cut surfaces pressed together will not adhere together as in ordinary caoutchouc; *thirdly*, it is not dissolved by any known solvents of ordinary caoutchouc, as bisulphide of carbon, naphtha, &c., the more powerful solvents merely causing it to increase in bulk—it may increase to nine times its volume, but recovers its original volume after evaporation of the liquid; *fourthly*, it is not affected by heat at temperatures below the vulcanising temperature (about 270° F.), and melts at between 390° and 400° F.; *fifthly*, it is not oxidised by exposure to air and light as ordinary caoutchouc; *sixthly*, it is more elastic; *seventhly*, whereas ordinary caoutchouc absorbs 25 per cent. of water, com-

mon vulcanised caoutchouc absorbs only 4 per cent., and if its excess of sulphur be eliminated only 6·4 per cent. At high temperatures, especially when in contact with metals, it gradually loses its flexibility, and generally there is disengagement of sulphuretted hydrogen; a little coal tar added before vulcanisation is said to obviate these inconveniences in a great measure. If it contain excess of sulphur—*i.e.*, sulphur mechanically mixed—its durability is thereby impaired, at about 248° F. this sulphur enters into chemical combination and renders the material brittle; the same effect takes place at ordinary temperatures, particularly if the material be kept quiescent, alternate extension and compression and friction tend to eliminate the excess of sulphur, and are therefore conducive to durability. Common qualities generally contain sulphur in excess, being made by the use of flour of sulphur only, the more exact processes being reserved for special purposes. The excess of sulphur may be extracted by solvents, as ether, benzine, or sulphide of carbon. Vulcanised caoutchouc is prepared in several ways, the following being those most generally employed:—

1. Caoutchouc is kneaded with 7 to 16 per cent. of flour of sulphur, the finished articles are subjected to a temperature from 266° to 300° F. for some hours, to a temperature of 234° F. for a time, and for a much shorter time to 300° F., or to steam at 4 atmospheres. This process is that of Mr. Goodyear, and is very commonly adopted.

2. In the Hancock process the fashioned objects are carefully dried, they are then immersed in a bath of flour of sulphur heated to from 266° to 300° F.; the objects are kept in the bath two to three hours, or they are kept in the bath heated to 234° F. until they have absorbed one-fifteenth of their weight of sulphur—the bath is then heated for a short time to 300° F. This process is useful when the material is in sheets, tubes, or other thin masses not differing much in thickness at different parts; if they do differ much it is stated there is liability to convert the thick parts imperfectly, and the thin too much, the latter being made hard.

3. In Mr. Parkes' process protochloride of sulphur is dissolved in forty to fifty times its weight of sulphide of carbon, the fashioned caoutchouc is immersed in this solution for a length of time dependent on its thickness—about two minutes being sufficient when this is about ·04″; the articles are then washed in water to remove the excess of chloride of sulphur. The bromide of sulphur is sometimes used, and its employment has some advantages, but after a time an acid re-action makes the caoutchouc hard and brittle. To prevent this it has been proposed to

use metallic oxides in particular litharge. This process is adapted to thin articles to which kneading with flour of sulphur is inapplicable.

4. The fashioned caoutchouc is immersed for three hours in a solution of polysulphide of calcium marking 25° Baumé, in a close vessel at 280° F.; they are then washed with a weak alkaline ley (60° Baumé). This process yields the correct degree of sulphuration, and is applicable to the nicest purposes when durability and general excellence of the product are of great moment.

5. The following process also gives the exact degree of sulphuration required:—100 parts of caoutchouc in rough layers is mixed with 4 parts of sulphur and 50 parts slaked lime, the ingredients are then thoroughly incorporated by pressure between rollers; the finished articles are soaked for an hour in water to remove excess of sulphide of calcium.

6. Vulcanised India-rubber frequently suffers a chemical change attributed to a kind of acid fermentation; the best modes of hindering such change is the removal of free sulphur by immersing the articles in boiling solution of caustic soda, or using processes for vulcanising which give the exact degree of sulphuration. The former mode is inapplicable to thin masses. M. Gérard proposed to mix 5 to 10 per cent. of lime and vulcanise by the Goodyear process; he termed the product alkaline V. C. Mr. Day recommended pipe-clay for the same purpose. The use of an alkali makes the material harder than ordinary vulcanised caoutchouc. Other matters are mixed with vulcanised caoutchouc, particularly antimony. Mr. Burke proposed the use of sulphuret of antimony; the advantages of its employment are—there is no efflorescence of sulphur at the surface, and the vulcanised products do not undergo chemical change in contact with metals.

362. A kind of vulcanised caoutchouc termed *indurated India-rubber, vulcanite,* and *ebonite,* is a very valuable material; it is merely vulcanised caoutchouc prepared in a particular manner. It has not the elastic flexibility of vulcanised elastic India-rubber; it may be worked like ivory; it is light, takes a high polish, is very durable; being tougher than ivory, it is less liable to be fractured by a blow; it does not require seasoning to give it permanence of form, and it resists solvents even better than elastic vulcanised caoutchouc. Ebonite or vulcanite is made by mixing caoutchouc with half its weight of sulphur; the mass is made homogeneous by kneading in a proper machine or between rollers, it is rolled into sheets or fashioned into other required forms, and exposed for two hours to a tempera-

ture of 212° F., and for four hours to a temperature of 302° F.; at the higher temperature it may be rolled. The following process is esteemed more highly than the above:—Selected India-rubber is softened by a temperature of 170° to 180° F., cut up, purified by treating it with solution of soda; it is then kneaded with 20 to 35 per cent. of sulphur, according to the degree of hardness required, the sulphur being added gradually and the kneading performed at 120° to 140° F.; the fashioned material is subjected to steam at 4·5 atmospheres during 8 to 12 hours, experience being necessary to ensure excellence in the product. Properly the term *ebonite* is applied when the material is composed of caoutchouc and sulphur only, when mixed with colouring matter the compound is termed *vulcanite;* the latter term is sometimes improperly applied to the material used as an insulator, which should be composed of sulphur and caoutchouc only. Ebonite can be cut with a saw, turned, and generally worked as ivory; it takes a fine polish, and if bent warm it retains the bent form when cooled. When polished its surface should be free from specks, otherwise it contains foreign matter or uncombined sulphur; its fracture should be conchoidal and not granular. Exposure to air and light causes oxidation of the sulphur with formation of sulphurous acid; to maintain the insulation unimpaired it should therefore always be coated with French polish or other solution of shellac. Ebonite is unsuited for uses requiring it to be exposed, as in outdoor insulators; it suffers decomposition as explained above, it becomes porous, and cracks; it is frequently applied to the stalks of insulators, probably with a view of increasing the insulation; but these coatings separate from the metal and crack when exposed, particularly in the tropics, this effect being probably favoured by combination of sulphur with the metal of the stalk. The legitimate use of ebonite is as an insulator in apparatus, and generally indoors. Ebonite in thin masses has great elastic flexibility under a bending load. Its specific gravity is about 1·31.

363. India-rubber is a better insulator than gutta-percha, and has a lower inductive capacity, hence many attempts have been made to employ it as an insulator, at first as ordinary and ultimately as vulcanised India-rubber. Fresh India-rubber contains water in such proportion that its insulating power is very low, and it is not a good insulator until dried. Unmasticated or virgin India-rubber appears to be more durable than the masticated material, it does not appear to be changed by contact with copper, if it does change, the alteration takes place very slowly. The Para gum is esteemed more durable than that from the East Indies, but it is much dearer; the latter is, however, suitable for vulcanising.

Virgin rubber was found to resist the action of raw and boiled linseed oil and Stockholm tar, whereas masticated rubber dissolved in the first, and was swollen and gelatinised by immersion in the others. Crude rubber cannot, however, be employed economically. It has been proposed to employ the liquid India-rubber, but the employment of India-rubber in this manner on a large scale is impracticable. Masticated India-rubber is applied to wires as follows:—The cauotchouc being formed into large square blocks is cut into tapes $\frac{1}{32}''$ thick, these are stretched and wound on the wire, the whole is then immersed in water at 140° to 150° F. to consolidate the rubber; the joints are so perfect that they cannot be discovered, and will not tear open. This process was employed by Messrs. Silver & Co.; the tapes may be half an inch to an inch wide, several tapes may be superposed, and each tape may form two or more layers. The objection to the above process is that heat spoils the material, prolonged exposure to heat causes it to become tarry. Naphtha and other solvents have been applied to the joints, but their use is very objectionable; the joints are not durable, the use of the solvent induces rapid deterioration. Mr. Siemens invented a method of putting on the caoutchouc without heat or solvents; the material was cut into tapes of suitable width, the wire, together with two tapes, were passed between two grooved rollers, the freshly cut edges of the tapes were pressed together, thus the covering had two longitudinal joints; in putting on two or more layers the joints of one layer were placed in the centre of the tapes of the next. Unless this joint be subjected to heat it may be torn open. As caoutchouc changes when in contact with copper, the copper must be covered by some material which does not act on the caoutchouc; in the earlier cables cotton, hemp, and similar materials were used to cover the copper, one short cable of this kind was found to work after being under ground twenty years, but the general results were not encouraging. Mr. W. Hooper invented a mode of forming the material into blocks by compression; after cleaning and washing the crude rubber, before masticating, compressing, grinding, or dissolving it, it is heated to 250° F. in a closed chamber for two hours; it is thus rendered much easier to grind and more soluble, and may be compressed into a solid block very similar to masticated India-rubber without previous mastication. Mr. Hooper also applied the tapes to the wires at a uniform temperature, (about 60° F.) Mr. Hooper plates the wire to be covered with India-rubber with tin or a tin alloy, either put on the wire after drawing or drawn down with the wire. The only mode of covering wires with India-rubber at present used to any appreciable extent for cables is that of Mr. Hooper;

the copper wire is plated, then covered with ordinary rubber put on spirally, over this is put on with a die a thin covering of a mixture of India-rubber and oxide of zinc, termed the *separator*—a compound of this kind is described by the inventor, it consists of two parts by weight India-rubber, and one part oxide of zinc, ground for three hours with heated rollers; over the separator the wire is covered with India-rubber kneaded with sulphur (termed the jacket), the whole is then subjected to steam heat of 350° F. for four hours. The inner covering is put on spirally, the jacket is put on longitudinally, or spirally, the application of the jacket protects the inner layer during the application of heat, the heating vulcanises the jacket and consolidates the whole, the separator hinders the sulphur from passing from the jacket to the layer in contact with the wire where it would combine with the metal. A trace of sulphur does pass through, as it has been found, and a film of dark-coloured matter has been observed on the surface of the conductor, but apparently not to an extent practically injurious. The core is joined by first laying on a tape of masticated rubber, then a tape of separator, and finally tapes of jacket, the joint is then subjected to heat to vulcanise the jacket. The following is a mode of making joints in Hooper's core:—The core is usually covered with a coating of felt, this is removed for about twelve inches from each end of the core by applying naphtha and brushing with a wire brush. The insulator is cut off to bare the conductor for two or three inches at each end, and the conductor is joined in the usual manner; but the solder used must have a melting point higher than the vulcanising temperature (300° F.), or it will run and spoil the joint in the process of vulcanising; any of the soldering alloys which melt at a sufficiently high temperature (Paragraph 387) may be used, pure tin is commonly used in India. The insulator is tapered down to the conductor on each side of the joint by cutting it with curved scissors; the taper is made about two inches long on each side, it should be made regular in figure and the surfaces kept chemically clean and free from moisture. A tape of pure masticated rubber is laid on helically from the separator at one end to the separator at the other end of the joint, and back again wound in the contrary direction; the ends of this tape are fastened by pressing them down with a heated knife blade or tooling-iron. Over the masticated rubber is wound on a white tape of separator, this is put on in one layer extending from the edge of the jacket at one end to the edge at the other end, and the ends of this tape are also made to adhere by the application of a heated tool. Over the separator is wound a tape of India-rubber, mixed with sulphur, this tape is coloured red for distinction, it is put

on in three layers, the last layer is extended for two inches on each side over the uncut core, the latter being seared with a hot iron before cutting the core down with the scissors to ensure chemically clean surfaces. The joint is covered with a tight sewing of strips of calico in two or three layers, the ends of these are secured with a thick India-rubber solution or sometimes preferably with twine; the joint is ready for heating to vulcanise the jacket. The tapes should be stretched and put on tightly, great care should be taken to make them lie closely so as to exclude air; the surfaces to adhere should be chemically clean, and the greatest care should be taken to keep these surfaces dry by working with dry hands and drying the conductor and each layer. The joint having been completed as described should be exposed to a vulcanising heat to vulcanise the jacket, solidify the joint, and cause perfect adhesion between the materials applied and the core at each end. After vulcanising one or more layers of the outer cotton, tape should be removed and the joint examined. As the steam jacket and other sources of heat used commonly in vulcanising, are expensive and difficult to obtain and use in telegraph work, the source of heat employed is commonly a bath of some mixture which melts at the required temperature; bees-wax saturated at a temperature of 200° F. with asphalt and strained has been used in India. The mixture is melted in a suitable vessel by means of a charcoal fire, it is then allowed to cool almost to the temperature at which it solidifies, the joint is then immersed, and the whole is heated gradually until the bath boils; the fire is then removed and the whole allowed to cool until the compound is about to solidify, when the joint is removed from the bath and immersed in cold water. The above will convey a general idea of the mode of joining India-rubber core; the manufacturers issue directions with the necessary material for joining core of the several patterns they manufacture; the precise details of jointing must evidently vary with the size and the composition and arrangement of the constituent elements of the particular sample of core to be joined. If stranded wire be used the centre wire of the strand is covered with separator, and the other wires are laid into this. As compared with gutta-percha, India-rubber has the following advantages :—It is not affected by elevation of temperature below 212° F., whereas gutta-percha core is softened at 120° to 130° F.; it is a better insulator, and has a lower inductive capacity than gutta-percha. It is more resilient and therefore far less liable to mechanical injury, a vehicle may be driven over rubber core without sensibly flattening it permanently. Hooper's core is much more durable than gutta-percha when exposed in the tropics; India-rubber core is more flexible than gutta-percha

core, and is therefore better suited for movable connections. The disadvantages of India-rubber are the following:—it absorbs more water than gutta-percha, both materials absorb much less in salt than fresh water, the absorption of gutta-percha is very slight indeed in salt water—this absorption is not found to reduce the insulating property to an extent of practical importance in thick masses, as ordinary covered wire, but in thin plates it seriously impairs this property. Hitherto India-rubber could not be safely joined, but this difficulty is got over in Hooper's core; the system of cooking under a jacket seems to effectually consolidate the whole without damaging the pure rubber by heat, and the joints made in the finished core appear perfect; India-rubber becomes viscid in contact with copper, but this is got over by coating the copper with tin, and although the rubber has been found slightly sticky this does not appear to occur to an injurious extent, and probably does not occur at all under water; the sulphur in the vulcanised rubber in some cases has been found to have slightly attacked the metal, but to an insignificant extent. India-rubber is affected by greasy matters which preserve gutta-percha, such as boiled and raw linseed oil. India-rubber is not uniform in quality as gutta-percha, and mixed qualities are inferior in durability, but this objection has no force if the rubber be vulcanised. Gutta-percha core can be more readily joined than India-rubber core, as the latter requires cooking; this is a great objection to the use of this material for underground wires in towns and for some other purposes, but is of less moment in the case of a cable. The great objection to the use of India-rubber was the fact, that as gutta-percha had been studied and was well understood, it was better to keep to the employment of this material than commence anew to risk capital on an untried material, gutta-percha having been successfully applied only after many costly failures; but at present there is more data on which to base a judgment; from information furnished by the manufacturers it appears upwards of 9000 miles of Hooper's submarine cables have been laid or are to be laid, including 5000 miles for the Great Western Company, and a sample cable was laid as long ago as 1863. There is much difference of opinion on the subject; the engineer can, however, now examine for himself into the respective merits of cables actually in operation. Various compounds of India-rubber with shellac, gutta-percha, and other matters, have been proposed from time to time; one of the best is Wray's compound, this is composed of shellac, India-rubber, and powdered silica or alumina, and about one-ninth gutta-percha; it is put on with a die, but is obviously inferior to vulcanised India-rubber.

SECTION III.—*Porcelain, Ivory, Paraffin, &c.*

364. PORCELAIN AND STONEWARE.—Glass, indurated caoutchouc, varnished wood, and porcelain and stoneware have been tried as insulating materials for land lines; but porcelain and stoneware are the only materials in general use. The materials actually used are several varieties of white porcelain and brown earthenware. Clay is the basis of porcelain and stoneware; it is a hydrous silicate of alumina, differing greatly in the relative proportions of alumina and silica; it generally contains mechanically mixed lime, magnesia, and small quantities of other substances, and is produced as a rule by the decomposition of felspathic rocks. The clay used for porcelain, termed *porcelain earth* or *kaolin*, is white or yellowish in colour, and retains its colour when baked; potters' clay used for stoneware is similar to the above, but coarser, and some kinds change colour in baking; both kinds of clay are infusible in the porcelain furnace. Clay alone is too contractile when acted on by heat to admit of it being used alone for pottery, as it would crack and warp in the kiln; it is therefore mixed with a silicious substance to reduce the contraction; the substance usually used is *flint powder*, prepared by throwing flints heated to a red heat into water to render them brittle, and then grinding them to powder. This paste is not fusible, and is therefore mixed with a flux; the flux used is a felspathic rock which is calcined, ground to powder, and mixed with the clay and flints; it is composed of silica, alumina, potash, and lime; chalk or some other salt of lime is sometimes added. The paste described softens slightly in the kiln and becomes translucent; when baked its fracture presents a semi-vitrified appearance—this is termed hard or genuine porcelain. If the fusible ingredients be in greater proportion and more fusible, the product is termed *soft* or *tender* porcelain. Hard porcelain is glazed with an earthy glaze, soft porcelain is glazed with a soft kind of glass containing oxide of lead. Hard porcelain is stronger, resists extreme alternations of temperature better, and has a much more durable glaze than soft porcelain. The composition of porcelain is varied by different manufacturers, but the nearer it approaches the hard variety described above the better is it adapted for insulators. Some insulators, as the so-called Prussian insulator, have a very vitrified fracture; others, as some English kinds, present the semi-vitrified appearance, shewing the paste has just softened in the fire. If the paste softens in the fire it is quite sufficient to prevent the absorption of water by the body of the insulator;

the use of an excess of flux should be avoided. Soft glaze is readily worn through if the line wire rests on the porcelain, and as the object of the glaze is to present a smooth surface which may be readily washed by rain, and to which dirt will not readily adhere, a hard earthy glaze should always be preferred to a more brilliant but softer description. *Stoneware*, like porcelain, is made of clay combined with flint powder and felspathic minerals, in some cases cement-stone or chalk is used to supply lime; the flux causes partial fusion at the heat of the kiln. Formerly salt glaze was always used for this ware, but some ware is glazed at present with an earthy glaze composed of flint, decomposed granite, &c. The composition of stoneware is greatly varied by different makers, but it appears that although stoneware has a characteristic semi-vitrified fracture, it contains less of the fluxing material than porcelain, and the vitrification is not therefore so strongly marked; for this reason only the best and specially made stoneware is suitable for insulators. This ware is cheaper than porcelain, and is extensively employed. The soft material is fashioned by throwing and turning, by making the paste semi-fluid and casting it, and by pressing the paste, made rather stiff, into moulds; the third mode is that employed for making telegraph insulators, as it produces the densest and strongest insulator, and reduces to a minimum the possibility of faults, such as cavities and cracks; the material is used as dry as practicable, and pressed into strong moulds with considerable force. The use of a stiff paste has also the advantage of reducing the shrinkage in the kiln; in statuettes, which must be cast, the shrinkage reaches 25 per cent. in volume, the result is considerable loss by warping and consequent enhancement of cost. Both stoneware and porcelain offer great resistance to crushing, but they are unsuited to resist a tensile load; thus in shackles and insulators the porcelain should be subjected to compression only. Porcelain is not suited to resist shocks, and care should therefore be taken when placing a load upon it to do so steadily; the iron caps of insulators serve to protect them against fracture from this cause, and they also help to keep the pieces together should the porcelain be accidentally cracked. If the line wire rest directly on the porcelain it wears off the glaze; this effect is also prevented by the iron hood. As porcelain is so brittle and deficient in tenacity, the use of a cement which expands destroys the insulators; cement of iron filings and sulphur is a most destructive material in this respect. The cements in use for cementing the cups of insulators are treated of in Chapter I., section 4; in some patterns the stalks are not cemented in; the Prussian pattern insulator has the stalk fixed with tow dipped

in petroleum—this must tend to deaden shocks, but the hemp shrinks and requires renewal after a few years' exposure; it is necessary before putting in the stalk to place a small pad of tow in the bottom of the hole—a precaution often neglected. Some insulators have a metal female screw cemented into them into which the stalk is screwed; this has some advantages, but is not necessary, and it increases the cost of the insulator. A very small crack in the porcelain of an insulator is sufficient to seriously impair its electrical efficiency, but the insulating power should not be impaired by injury to the glaze alone; thus before testing the electrical value of an insulator a large patch of the glaze should be ground through. The glaze should simply act mechanically to preserve the insulation. If the edge of an insulator cup be rounded, as 1 (fig. 66), water does not so readily drop off as from a sharper edge, as 2. It is also an advantage for the outside surfaces of the cups to be as nearly perpendicular as possible, as they are then more readily washed by rain, and less dust remains on them. Insulators which have several concentric cups are difficult to clean and examine; these can only be cleaned by removal from the line. For short lines in towns single cup insulators are suitable; they are cheaper than the double cup patterns, easier cleaned, and have ample resistance; but for long lines double cups are employed. Insulators fixed by screws through ears wholly of porcelain or stoneware are sometimes used for thin wires; they are unsuitable when thick wires are used.

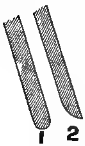


Fig. 66.

365. Horn.—The use of horn in telegraph instruments has been generally superseded by that of ebonite; but horn is often much cheaper, more easily procured, and well varnished it serves very well for common instruments, or for temporary purposes. Horn may be cut cold with a saw, and when heated it may be fashioned with a knife as easily as deal; it is distinguished from bone by containing a greater proportion of gelatine.

366. Ivory and bone.—Bone has to be purified before it can be employed, and as it is purified by the action of hot water it loses a portion of its gelatine, and has its original strength and elasticity impaired by the process. Ivory has less gelatine than bone, but it does not need purification; it is stronger and denser than bone, and is free from pores. It requires seasoning like wood, it shrinks both longitudinally and transversely, the former much less than the latter; it shrinks unequally in the directions of the tangent to and radius of the cross section of the tusk. It absorbs water to a very slight extent. Ivory is cut with a saw fitted in a steel frame—the blade should be 15 to 30 inches long,

from 1·5 to 3 inches wide, and about ·02 inch thick; the teeth should be five or six to the inch, sloped a little forward, slightly set, and very sharp; the saw should be lubricated with solid fat, and at entering it should be guided very correctly, and with no pressure but that of its own weight. Ebonite is cut in the same manner as ivory, but being cheaper less care is taken to avoid waste, and being without organic structure ebonite is not so likely to split; it is easier to cut up than ivory. Ivory is most frequently used turned, it is used for labels, handles, &c., outside, and as insulating material inside telegraph instruments, as galvanometers, relays, &c.; it has been largely superseded as an insulating material by ebonite, but is still used and will probably continue to be used as an insulator for lining small holes through metal plates, &c. Ivory is best joined by cement made of isinglass dissolved in dilute alcohol or gin, by simmering in a water bath for an hour.

367. PARAFFIN, from *parum affinis*, is a fatty substance, as its name implies chemically very stable and indifferent. When pure it is solid, inodorous, tasteless, colourless, and translucent, somewhat resembling spermaceti, but with less apparent crystalline structure. Specific gravity ·870; it melts at from 113° F. to 149° F., forming a thin colourless oil; it boils at 698° F., and with care may be volatilised without decomposition. It does not absorb oxygen from the air at ordinary temperatures; it burns with difficulty without a wick, readily and brightly with one. Paraffin is insoluble in water, soluble in 2·85 parts of boiling alcohol, but it separates completely on cooling, forming snowy crystals; it is much more soluble in ether and in oils, it is not attacked by chlorine unless melted; it resists dilute nitric and sulphuric acids, it is attacked but slowly by strong sulphuric acid even at 212° F., it is decomposed by strong nitric acid aided by heat. Paraffin is the solid portion of the mixture of oily hydrocarbons produced together with other substances, by the destructive distillation below a low red heat of different organic bodies and bituminous minerals; it is also a constituent of many varieties of petroleum, and is found native in bituminous strata. The actual sources of supply of paraffin are—tar obtained by distilling coal, bituminous shale, peat, and mineral oils. It is probably a mixture of several hydrocarbons; its ultimate composition varies with the source of supply, the percentage of carbon varying between 84·60 and 85·31, and of hydrogen between 14·23 and 15·4. Paraffin is used to protect covered wires forming the connections of electrical instruments; gutta-percha and caoutchouc covered wires may be thus protected from contact with the air, and have their original insulation readily

preserved; the paraffin is poured into the base board containing the connections to be protected, so that when it solidifies the connecting wires may be enclosed in a solid block of paraffin. Melted paraffin spread thinly on absorbent bank post paper, forms a dielectric much used in making condensers or accumulators for ordinary use in telegraph offices, tinfoil and paper saturated with paraffin are alternated, and the required extent of surface having been arranged in this manner, the whole is enclosed in a suitable box, which is then filled up with melted paraffin to form a solid mass. Paraffin used in the manner described serves not only to preserve the insulation, but to protect thin sheets and wires against mechanical disturbance.

368. Drying Oils.—Drying oils are fixed oils which have been boiled with a metallic oxide, usually litharge, an oxide of lead; the metallic oxides commonly used are technically termed *dryers.* Oil so treated when used as a varnish quickly dries and leaves a coating of varnish; these oils are used in painting for varnishing out-door woodwork, &c. Factitious gum used for making catheters and other surgical instruments, is made of drying oil rendered thick by prolonged boiling; japanned leather furnishes another example of their employment, the varnish being very flexible and not liable to crack when the work is well done. Drying oil is an excellent varnish for wires covered with silk or cotton, but it is not generally used as an insulator; this with other matters used as flexible varnishes deserve consideration by the telegraph engineer. Mr. William Hooper has obtained provisional protection for the application of a compound adapted to telegraph purposes; the specification is numbered 3780, and dated the 20th of November, 1873, and the following description is from the specification:—The object of the invention is the preparation of a compound for applying to cables, either directly to the conductor or over another insulator, preferably India-rubber, and suitable for applying with cotton, tape, or other fibrous material, and for covering wires generally. The compound is obtained from the distillation of cotton-seed oil, or the "foots" of this or any other vegetable drying oil; the soft tar or oil is oxidised by nitric acid aided by heat, and mixed with hard pitch obtained by distillation of cotton-seed oil, or other vegetable drying oil. The compound is sufficiently fluid for use at 300° F., it is a good insulator, unaltered by water, tough and not readily cracked by bending, and free from naphtha, tar, pitch, and other materials likely to impair the insulating property of India-rubber. The inventor also saturates the fibrous yarns used in telegraph cables with soft pitch, obtained by the distillation of cotton-seed oil, or other vegetable drying oil. Messrs. Hooper and Dunlop, the

inventors, state they sometimes substitute for soft pitch oxidised by nitric acid, a closely-resembling material "*oudroic*," obtained as a bye-product from the distillation of matters containing stearine, and chiefly imported from Holland. Another compound has been invented by Mr. Madsen, it is described in the specification as suited for use as an insulator in cables. It is composed of one part by weight wax, one-half resin, three-fourths paraffin, one-half crude turpentine, and one-eighth tallow. For saturating tapes the inventor uses one part Stockholm pitch, one-fourth wax, and one-eighth tallow.

CHAPTER IV.

Operations and Manipulation, including Drawing and Surveying.

Section I.—*Ropes and Chains; Straining Wires and Raising Heavy Bodies.*

369. The best blocks for telegraph purposes have iron shells, brass sheaves, and steel spindles; they should be as light as consistent with strength. Chains are not used for raising weights or straining up lines, as the tension in these cases is not so great as to render the use of them advisable; but they are used for lashings, as stays for standing masts, &c. Chain is of two kinds—*crane chain*, in which the links are small and oval, and *chain cable*, in which the links are somewhat longer and have a stay or stud inserted transversely in each link. Oval-linked chain is seldom used of iron above an inch in diameter; the weight of this chain in pounds per fathom is as follows:—

$\frac{3}{8}''$ 8·5; $\frac{1}{2}''$ 14; $\frac{5}{8}''$ 24; $\frac{3}{4}''$ 32; $\frac{7}{8}''$ 44; $1''$ 56.

For particulars concerning the strength and distribution of stress in chains, see Paragraphs 97, 318, and 331. When chains are used as lashings they are wound several times round a picket, timber head, or other suitable body, and the end is secured with yarn; or the chain may be loosely knotted and the end secured in the same manner. Small chain in short lengths is sometimes used with straining winches.

370. Ropes are made from hemp or Manilla; hemp fibres vary from 3 to $3\frac{1}{2}$ feet in length; these fibres are twisted right-handed

into yarns, the yarns left-handed into strands; three strands twisted right-handed form a hawser rope. The twisting causes so much friction between the fibres that when subjected to tension they are not drawn asunder, but the force is resisted by all the fibres together. Formerly ropes were twisted by hand, aided by very simple appliances, but now most ropes are made by machinery. Ropes are distinguished in size by their girth in inches—*e. g.*, a 10-inch rope is a rope 10 inches in *circumference.* Hand-made ropes are about $7\frac{1}{2}$ per cent. heavier than machine-made, both containing the same number of yarns and measuring the same in girth. Machine-made rope is however the stronger, for the machinery so twists the yarns into strands, and the strands into rope, that every part is equally strained when the rope is loaded. Machine-made ropes of different sizes are equal in strength per unit of sectional area, but hand-made ropes differ widely—*e. g.*, the difference of strength per unit of area was found 33 per cent. less in an 8-inch rope, than in a 3-inch rope of the same quality hemp. Ropes made without tar are called white ropes; tarred ropes have the yarns passed through the tar hot or cold. Tarred rope is weaker than white rope, that tarred cold is about 25 per cent. weaker; ropes tarred hot are 16 to 20 per cent. stronger than those tarred cold, and they are equally strong per unit of area in different sizes, but the strength of ropes tarred cold varies widely in different sizes; this difference of strength is 14 per cent. between an 8-inch and a 3-inch rope in favour of the latter. Tar acts on the strength of rope by diminishing the friction between the fibres, and by acting chemically on them; tarred ropes maintain their strength longer than white ropes, particularly when exposed to water; but to ensure this result the tar must be freed from acid matter likely to destroy the fibres, otherwise the tar is very prejudicial, hastening the decay of the rope, so that in warm climates the rope becomes useless in about three years. Messrs. Chapman of Newcastle proposed boiling the tar with water to remove the acid and mucilage, then concentrating it by boiling, and thinning it down with fat or oil. Navier states that tarred cordage, deducting the weight of tar, is as strong as white rope of equal weight; that the tar diminishes the strength of the rope with time and makes the tarred rope less durable than white rope; the same author states that saturating cordage with fat or oil weakens it without increasing its durability. Tar is now carefully purified, so that it is not so destructive, and machine-made ropes are more constant in strength; the immediate effect of tar on rope has probably been exaggerated, but there can be no doubt that carefully prepared it acts as a preservative. The quantity of tar by

weight varies between 15 and 21 per cent. of the weight of the hemp. White ropes being more flexible are perferred to tarred when required to pass over pulleys. In India Manilla ropes are used, they are about as strong as tarred hemp, and are more durable than untarred hemp; they are often saturated with a preservative, probably some stable fatty derivative from petroleum. Authorities differ very widely in stating the strength of ropes. Rankine states "hempen ropes" have a tenacity from 12,000 to 16,000 lbs. per square inch, these are presumably untarred; he states the strength of a 1-inch hawser at 1,050 lbs., equal to about 13,000 lbs. per square inch. Glyn's old ropemaker's rule gives 5,622 lbs., this is for hand-made rope; Morin states the French rule for tarred cordage is 6,150 lbs.; Captain Huddart's experiments gave 7,293 lbs. for a 3-inch and 5,473 lbs. for an 8-inch rope hand-made of common hemp, and the tenacity of ropes of the same sizes of Petersburg hemp were 8,710 and 6,500 lbs. respectively; machine-made ropes were stronger—*e. g.*, 3-inch tarred cold 12,155 lbs., tarred hot 12,480 lbs., 8-inch cold register 10,660 lbs., hot 12,480 lbs.; Navier's experiments gave for a cord rather above 1·6 inches 13,514 lbs., for a 2·1-inch rope 12,092 lbs., for a 6·68-inch rope the strength was only 6,899 lbs., intermediate sizes gave intermediate results; the mean of the series of experiments was 9,947 lbs. per square inch. Mr. Anderson (*Strength of Materials*) states the strength of ropes is usually considered be be about 6,400 lbs. per square inch; this is a high value for hand-made rope, but too low for machine-made rope generally used, nor is it generally accepted, as appears from the above authorities. The same writer states the results of recent experiments made at Woolwich were from 9,874 lbs. in a 9-inch to 10,783 lbs. in a 2-inch rope. Considerable difference in strength was found to exist in ropes cut from the same coil, the actual tenacity of 4-inch ropes varied from $5\frac{5}{8}$ to $7\frac{15}{32}$ tons, 6-inch ropes from $14\frac{1}{4}$ to 17 tons, and 9-inch ropes from 25 to $29\frac{11}{16}$ tons. After being used the strength of an apparently good 6-inch Italian hemp rope was 10·75 tons, that of a similar new rope was 14·25 tons; an old 6-inch Russian hemp rope broke with 5·5 tons, a similar new rope with 11·25 tons. The great differences in the above figures are explained by the ropes being very different in quality, some were machine-made, others hand-made, some of the ropes (or the hemp composing them) had been in store, others, as in Captain Huddart's experiments, were quite fresh. Captain Huddart's results are the mean of three hundred experiments, and the values obtained for hand-made rope are confirmed by other authorities; for the machine-made ropes the values approach those adopted by Professor Rankine. The

strength of new hand-made rope varies with its size: if of good quality it is about 6,000 lbs. per square inch for 7 or 8-inch rope and may be 8,000 lbs. for a 2 or 3-inch; machine-made ropes tarred cold 10,000 to 12,000 lbs., tarred hot the strength is very constant and about 12,000 lbs.; white rope, machine-made, above 12,000 lbs., attaining the values given by Professor Rankine. The above refers to hawser-laid rope, the most solid kind of rope made; three hawsers laid together left-handed form a cable. By reason of the interstitial spaces being proportionately greater, if the completed cable be measured the tenacity calculated on this measurement will be proportionately less than that of the hawsers taken separately; thus the tenacity of cables is about 9,000 lbs. per square inch calculated on their girth. Shroud-laid rope is composed of four strands laid on a central heart or core. The above figures apply only to new ropes made with new hemp of good quality; if the hemp be kept in store before or after being made into rope, there is rapid deterioration, ropes which have been long in store should therefore be tested before use; a perfectly new $3\frac{1}{2}$-inch white rope which had been sometime in store in India kept dry, but exposed to the light, broke with at most one-seventh of its ultimate load when fresh. If common hemp be used the above values must be reduced. Ropes should be kept dry and in the dark, they should be aired periodically; if on opening the strands the centre smells musty and appears discoloured, the rope is damaged. To test a rope entire is difficult, requiring great weights or heavy machinery; about a yard should be cut out and several of the inside and outside yarns tested by using them separately to suspend a weight. In testing ropes supplied by contract the inner yarns should be most carefully tested, and the piece cut out should not always be from the end but preferably from the middle of a coil. All doubtful ropes should be tested, and ropes taken from store should be tested before use for heavy loads. Ropes deteriorate rapidly in use, probably from injury to the outside by friction, cutting, &c. Italian hemp is somewhat stronger than Russian, white Manilla rope is about 25 per cent weaker than hemp; best quality hemp is 20 per cent. stronger than common staple hemp. Jute is sometimes used as rope, often roughly made up by hand; it is very inferior in strength and durability to hemp. Cocoa-nut fibre termed *coir* is also used for rope; this rope is very inferior in strength, but is very elastic and durable when exposed to wet, therefore it is much used for cables. Ropes are proved to half their ultimate tenacity, and worked to half their proof strength for a dead load. Mr. Anderson states the factor of safety is 5 as the results of the Woolwich experiments. If the rope be tested and new 4, and

after use for a short time 5, should be used; if the rope be worn or otherwise injured full allowance must be made for such deterioration, the rope being tested occasionally; the factor for a live load should be 10. Ropes are joined by a long or short splice, the former is used when the rope has to reeve through a block; a short splice is also used to make an eye on the end of a rope, in which case it is termed an eye-splice. The ends of ropes should be served with yarn or thin wire by means of a serving mallet to prevent the rope opening and wasting. The tools used for splicing and serving rope are the marline spike and serving mallet; serving and splicing are best learned from personal instruction; joins and eyes in tackle ropes should be *spliced*, as knots are apt to catch the plies. The best knots are those which do not jam (as they are readily untied), and yet do not slip when strained; as knots in thick ropes cannot be drawn tight they may be hammered close with a mallet, and the end should be secured to the rope with yarn. Long ropes should not be unnecessarily cut, as they cannot be joined again as before.

371. Line wires are held and attached to straining tackle by claws, eccentric tools, or a kind of vice; the leverage of the claws being short, they are liable to slip under considerable loads. Both the ordinary claws and the vice injure the zinc coating of the wire; draw-tongs with the jaws guarded by pieces of hard wood would probably be found an improvement on the patterns in general use. In India rope stoppers are generally preferred; they do not injure the wire nor slip, but they take a longer time to adjust than the vice or claws. Rope stoppers are of two kinds: that most generally used is a piece of rope 3 or 4 feet long, one end is served with yarn or wire, the other end has an eye-splice in which to insert the hook of the straining tackle; the rope used is generally $3\frac{1}{2}''$ tarred rope. This stopper is used by partly untwisting the rope and laying the wire between the strands for $1\frac{1}{2}$ to 2 feet, securing the ends of the stopper to the wire with thin wire or yarn. The other kind of rope stopper is only used when the rope at hand is too thin for

Fig. 67.

the first kind, as it takes longer to adjust and is more liable to slip; this is made by doubling a piece of rope and putting on a serving of wire or yarn round the double rope near the bight; this stopper is applied as shewn in fig. 67, by being crossed

alternately over and under the wire AB; it is secured to the wire at several of the places where it is crossed with yarn or wire, and the tackle hook is inserted in the bight C. For rope stoppers $3\frac{1}{2}$-inch tarred rope, for ordinary straining tackle $2\frac{1}{2}$-inch, and for light portable tackle, used only occasionally for repairing lines broken by accident, $1\frac{1}{2}$-inch white ropes, are sizes found convenient in practice; each length of rope for ordinary straining purposes is 40 to 50 yards. The sizes of ropes given above are for straining heavy wires, as No. 4 or even larger, but the size may be reduced when the line wires are all thin, as Nos. 9 to 12. The blocks used together are either one single and one double, termed a luff-tackle purchase, or one double and one triple, termed a gun-tackle purchase—the ply of rope hauled on is termed the tackle fall; the former tackle is lighter, and should be used when portability is of importance with the thin rope, the advantage in power is about 3; the second tackle has the advantage of preventing the line being strained in jerks, and the advantage in power is 5. Tackle should be hauled on steadily and not in jerks; it is often very difficult to get this in India with coolies, hence the gun-tackle purchase is preferred; in Europe, with more skilled labour, the lighter and quicker tackle should be preferred. For hauling up wires at terminal posts a winch with a ratchet is commonly used; a short length of rope, chain, or strap winds round the barrel, and carries a vice or claws to seize the wire; in India the ordinary tackle is more generally employed, but the winch is more convenient for town lines, particularly when the wires are thin and numerous.

372. The largest timber mast necessary to raise in one piece does not exceed 70 to 80 feet in length, but standing masts seldom exceed 60 feet; sheet-iron masts exceeding 60 feet in length are seldom raised in one piece. Timber masts are more difficult to raise than iron ones, because the timber mast is not only usually heavier, but the matter in it is distributed over its whole length, whereas in an iron mast the base is usually cast iron, and a large proportion of the weight of the mast is hence concentrated in the lowest part. In erecting telegraph masts heavy blocks and thick ropes should be dispensed with as much as possible; they are expensive to purchase and carry, not generally useful, and the ropes deteriorate with keeping; smaller rope in a greater number of plies should be substituted when practicable. Masting shears cannot be carried, if necessary temporary shears must be made on the spot; neither capstans, windlasses, nor crab winches are usually obtainable, hence it is necessary to work safely and efficiently with very simple

appliances. In raising a mast the lifting force required should be reduced by avoiding to lift the foot of the mast off the ground; in masting a ship it is necessary to lift the mast clear, but the heel of a telegraph mast need not be lifted from the ground, while if the mast to be raised be of iron with a cast-iron base, the extra weight of the foot may be made to assist in raising the mast. If an iron mast has to be built up in small pieces, the pieces are usually tubes with angle iron flanges, and bolts through the flanges are used to fasten the pieces together; in this case, after the hole has been dug and the foundation prepared, the cast-iron ground tubes are lowered into the pit by means of a derrick erected a short distance from the hole, the top of the derrick being over the hole. A derrick consists of a single spar of suitable length, seldom exceeding about 30 feet, inclined slightly from the vertical, and held by three ropes fastened to its head; one termed the stay in the plane of the spar prevents the spar falling in the direction of its inclination, the others are termed guys, and are fastened in a line passing under the head of the spar, and at right angles to a line from the foot of the spar to the anchor of the stay; the derrick is used by hanging a tackle from its head, the head may be moved by hauling on one guy and slacking away the other, but this motion is not required when lowering small weights into a hole. The derrick is generally used for weights up to about a ton, but is also sometimes used for greater weights. The stay rope should be anchored a considerable distance from the spar; the foot should be secured from slipping by being placed in a hole, and should not be so near the edge of the foundation pit as to crack the soil; if the latter is feared the pressure should be distributed by planks. A gyn or gin consists of a spar standing vertical, and kept so by four guy ropes from its head, anchored a considerable distance from the spar, the anchors being at the corners of a square of which the foot of the spar is at the centre; this arrangement is very useful for raising small masts, and for lifting the pieces when building large masts. When an iron mast has been built above the ground level it should be continued as far as possible by means of the gyn resting on the ground, the spar is then raised by means of a tackle attached to its heel and to the upper part of the completed portion of the mast, the spar of the gyn becomes a kind of temporary topmast; as the mast is built the spar is raised, until the mast is completed. In the manner described large masts are built without scaffolding, and at far less expense than they could be raised in one piece; as the spar is raised the guys have to be gradually loosened, but in all cases rope lashings should be put on to

prevent the gyn spar toppling over while being lifted, the guys alone should *never* be relied on; the fall from the lifting tackle should reeve through a snatch block near the ground, that the men may haul horizontally and keep from under the load lifted. Chain or rope lashings may be used to support the spar and attach it to the mast while the pieces of the mast are being raised, but wrought-iron clamps are more convenient; these clamps consist each of two rigidly connected rings in the same plane; the rings are closed by screwed bolts that they may be tightened round the mast and spar respectively; two clamps are used at a time, placed a short distance apart; the lower acts as the trees, and the upper as the cap to the standing mast. Each piece of the mast as raised has two light girt-lines attached to it, to enable men on the ground to keep it clear while ascending, and guide it into its place when raised high enough. When a mast has to be raised in one piece it may be done economically in the following manner:—The foundation pit being dug and the foundation prepared, a cutting or trench should be made, opening at one end into the pit; this cutting should be very little wider than the diameter of the foot of the mast, its sides should be as nearly perpendicular as the nature of the soil will allow, and its bottom should slope at an angle of about 45° down to the level of the bottom of the pit. The heel of the mast to be raised should be laid over the trench, its end being just within the pit; if the mast be a light sheet iron one with heavy cast-iron ground tubes, then the cast-iron part should be supported by pieces of timber placed across the trench until the mast is about to be raised. Four guy ropes are attached to the head of the mast; these are carried to strong pickets, anchors, or trees, which should be at a considerable distance from the pit; two should be in the common direction of the trench and the mast as it lays on the ground, and two should be in a line at right angles to this direction, passing through the centre of the pit; to the line passing to the side of the pit opposite to the trench, a strong tackle is attached to raise the mast when it has been lifted by other means to a considerable angle with the ground. It is necessary to fix the heel of the mast to prevent it from falling forward suddenly into the hole, and to so control its descent as to place it in the centre of the pit; this is best done by strong rope attached to the heel of the mast, the ends being wound two or three times round two strong pickets placed one at each side of the trench, but a short distance from it, in strong ground. Having made the above arrangements, the mast is raised by the head by any of the means described below; when partly raised it has a tendency to slip into the hole, the

ropes attached to the foot are held and gradually slackened, so as to cause the heel to fall exactly into the centre of the hole; the side guys are kept fast as the mast is raised; when the top of the mast is high enough, the tackle attached to the front guy rope is used to complete the raising, it is hauled on gradually while the opposite guy is gradually slackened, the pit should be at least half filled, and then by means of the guys the mast may be placed truly perpendicular. The mast may be raised the first stage by any of the following means:—If light, particularly if of sheet iron with a cast-iron ground tube which partly balances the wrought-iron tubes, hand shears may be used; these are commonly used in India when bamboos are readily procurable, they are made of two bamboos or other light strong wood, tied together near one end, and crossing each other like the blades of a pair of scissors—six, eight, or more pairs of sticks are so tied, varying in length from about 4 feet to perhaps 30 or 40 feet; the smallest shears are placed like trestles under the end of the mast, these are pushed towards the foot of the mast as larger shears are introduced, until several pairs are under the mast; two men hold each stick, and as some lift others push their shears further under the mast until it is gradually lifted. Light masts, up to about 45 feet, may be lifted entirely by hand shears, and in India they are generally raised in this manner. To ensure success the side guys should be carefully looked after to prevent the mast being pushed to one side, when it might fall; a full number of shears should be used, both to support the weight and because they are apt to break; the lifting should be done in short spells, all the men then work together to the sound of a whistle or the voice. In America pike poles are used instead of hand shears to lift wooden masts; a pike pole is simply a light pole with an iron spike at one end. The mast to be raised is pushed up by means of a number of these poles, the spike being driven against the mast prevents the pole slipping off; pike poles are not so safe as hand shears, and when many men are employed together the pike pole is very dangerous, as the men are obliged to keep close under the weight to be raised; shears should always be preferred when obtainable. This mode of raising a mast is not suited to very heavy masts, it then becomes dangerous to the men, but it is especially adapted to light iron masts likely to bend in lifting if not well supported. A light mast may be raised by a tackle attached to a gyn, this is somewhat more speedy and requires fewer men than with hand shears; it requires a good spar and a quantity of rope for guys; the spar should not be erected near enough to the hole to crack the earth. Heavy masts are raised by means of shears or shear legs, these consist of two stout poles

strongly lashed together near one end, they are erected to form an acute angle over or near the foundation pit, and are kept in a perpendicular plane by two guy ropes from where they cross, placed in a plane perpendicular to the common plane of the spars; a strong tackle is suspended from the lashing where the spars cross, and this tackle is used to raise the mast. Planks may sometimes be used with advantage under the spars, or the latter may be buried for a few inches in the ground; to economise rope the proper permanent guys of the mast should be attached before the mast is raised, and these should be temporarily lengthened with any piece of rope available, so as to serve as girt-lines to control the motion of the mast as it is raised; these lines should be wound round strong pickets, and slacked away or taken in according to circumstances. The shear legs are raised by hand shears or by small shear legs; the strength of timber necessary, and the load on a pair of shear legs or a derrick pole, may be calculated by formulæ given in Part I., Chapter ii., sections 2 and 6, and Chapter iii., section 2—*e.g.*, a derrick pole and its stay rope together supporting a weight presents a case of the triangle of forces; the weight and the stresses on the spar and the stay balance each other, and are related as the sides of a triangle; if a pair of shears be inclined, this is a similar case, the two shear legs act together as a strut and are equally strained; if the shears be kept vertical the weight is balanced by the equal stresses on the legs; the transverse leverage on an inclined spar varies as the cosine of its inclination to a horizontal line, &c. Pickets for fastening ropes to should be of stout wood and have rather long points; they are best put in by jumping a hole the size of the picket, and then driving the latter with a mallet. Two or more pickets may be used connected by cord as shewn in fig. 68, tent pegs may be secured in this manner during storms; ordinary marine anchors are useful, but they are not portable, and hence are seldom at hand. To avoid accidents to men engaged in using tackle, particularly when the men are ignorant coolies or others unused to such work, while the tackle is strained the men should be so placed as to be as safe as possible in case of accident; this rule should be invariably observed, and not only when the load is very great, as in lifting masts or straining river crossings—*e.g.*, no one should be under a line being tightened, nor inside the angle formed by the line wires while the tie of an angle post or the post itself is being repaired.

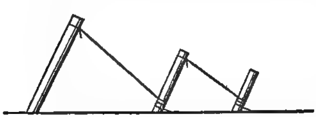


Fig. 68.

SECTION II.—*Tools and Mechanical Manipulation.*

373. The angles of cutting tools vary between about 20° and 120°, being varied principally according to the hardness of the substance to be cut. If the chip be too rigid to bend as the edge of the tool proceeds, the cleft will precede the tool, and the substance will be torn or split; in order that the substance may be cut the edge of the tool must be thin and sharp, and applied to remove only a thin shaving at a time, or it may be guarded as in the plane, in which the edge of the mouth and the top iron bend the shaving and prevent it being torn off. Felling axes, choppers, hatchets, bills, dhaws, and chipping chisels, have strong blades bevelled on both sides, they are required to be but moderately accurate; but plane-irons, paring chisels, adzes, gouges, scissors and shears, and generally tools required to have accurate edges, are bevelled on one side only. The object of this in chisels, plane-irons, and adzes, is that the flat side of the blade may be used next the substance to be cut, and thus the angle between the blade and the material may be more acute and the shaving thinner, than if the tool were bevelled on both sides; and in all single bevelled tools, the edge is much easier kept accurate by grinding, for one surface being made accurate at first and never afterwards altered, it remains so; even if the tool be badly ground the edge can only be made inaccurate in one plane, and that the less important one. For example, the circular form of the gouge, the inner surfaces of shear blades, and the flatness of the chisel blade, are unimpaired in the plane of the incision by inaccurate grinding; but this would not be so if these tools were bevelled on both sides, in that case departure from the correct form could not ordinarily be avoided. In unskilful hands the best felling axe is a narrow bladed one with a slightly rounded rather thick edge; to use the wide axe with a thinner edge requires more strength and skill, and if clumsily used its edge is soon either bent or broken. Axe blades should not be so hard as to break or chip. Bills and dhaws should be heavy, the blades should not weigh less than two pounds; the centres of inertia and percussion should be much nearer to the end of the blade than to the handle, in order to gain the advantage of the centre of inertia being placed far from the axis round which the instrument is swung. The curve of the blade should be continuous, this causes the edge to enter the wood gradually and makes the instrument cut easily; many bill-hooks are improperly made straight in the blade up to near the end, where they are hooked instead of being curved from the handle. The ordinary English bill is useless for jungle clearing—it is too light, too thin, and badly shaped. In general the best pattern axe or bill is that the men are used to—*e. g.*, in

India the native patterns should be preferred for the natives; but the native made tools have very little steel in them, and they are soon worn out by sharpening—they should be made to order under strict supervision. For cutting high jungle grass the most economical tool is the sickle, an instrument with fine teeth, acting like a fine saw. Tools used for clearing forest or jungle are frequently lost, for if laid down by the men they are difficult to find; they are easier found if the handles are painted a bright red. When a large number of men are required to cut jungle many villagers can generally be engaged to bring their own tools, but these are sometimes bad, and a small supply of clearing tools is necessary in all cases. In England and France an eccentric cutter fixed on a long rod and worked by a line is used to cut small branches of trees touching line wires, such an instrument is only necessary in towns. A small bill-hook firmly lashed to a rod serves this purpose very well. Tools for wood are bevelled at angles usually between 20° and 45°, according to the hardness of the wood to be worked and the manner of working it; paring chisels and gouges are bevelled to about 30°, plane-irons 35°. The bed in planes is the surface on which the iron lies, the angle of this bed with the face in bench planes is 45° or common pitch for deal and other soft woods, and 50° or York pitch for hard or stringy woods; for box and ivory the iron may be vertical or slightly forward, the angle being increased as a general rule with the hardness of the material. Most wood may be planed better from one end than from the other; this fact should not be overlooked when shifting the wood or turning it over while planing it. A most useful chisel in telegraph work is the mortise chisel, it is thicker and stronger in the blade than the paring chisel, and has an iron socket into which a wooden haft is fitted to deaden the blows of the mallet used to drive it; this chisel is useful for cutting mortises in making ladders and letting fittings into wooden poles, it has a more obtuse bevel, and consequently a stronger edge than the paring chisel, but is liable to be chipped, being generally too hard; it should therefore be lowered in temper as a rule. The chisel is commonly used with the bevel from the freshly cut surface. Cutting tools for turning wood have angles from 30° to 45°, tools for cutting iron from 60° to 70°, for gun-metal and brass 80° to 90°.

374. Scissors and shears for soft flexible materials have edges commonly 90°, seldom less than 60°; the blades should be curved and not straight; they may be loose when at right angles to each other, but should begin to cut near the joint, they should not be loose when they are sufficiently closed to cut, and they should leave the cut edges exact. Shears for metal act somewhat differently from scissors, they force the material asunder; their

edges are more obtuse than those of scissors, and are seldom more acute than 80°; they commonly have straight blades. It is of primary importance that the edges of scissors and shears meet, as if they are separated the labour is enormously increased, the material is torn, it gets between the blades, becomes jammed, and with metal shears the bar or plate is tilted and the shears are strained, or perhaps broken. In working India-rubber or gutta-percha, bent scissors should be preferred; to cut India-rubber they should be used wet, but for gutta-percha they are only required to be wet when the material to be cut is soft.

375. Cutting tools are sharpened on the grindstone to remove the greater part of the material, and tools for working the softer materials, and finishing tools for metals, are finished on the oil-stone; but cutting tools for iron are not usually finished on the oil-stone, because although the edge cuts better, it is not so durable. Tools for brass and gun-metal are always finished on the oil-stone, because otherwise they drag. Finishing tools are sometimes burnished. The grindstone should turn truly and should not be suffered to wear eccentric, should it become so it must be made true; for grinding large flat surfaces the stone should be of large radius, otherwise the surfaces will be ground sensibly concave. The oil-stone should be worn equally to keep it flat, but if it wear unequally its surface must be levelled by rubbing it down on a stone or iron plate; the oil used should not be of a kind likely to deposit resinous matter on the stone. The grindstone may turn to or from the edge of the tool; the former is preferred when practicable, as the latter causes the extreme edge of the tool to be wired—*i. e.*, to curl up away from the stone. Tools are always held with the edge to be ground across the edge of the stone and parallel to its axis, because by this means the edge of the tool is ground concave to the radius of the stone, in which condition it is better shaped for finishing on the oil-stone, and for wood tools this slight concavity makes them cut better; but broad flat surfaces are moved quickly to and fro across the stone to prevent them being ground concave—a result readily produced if the tool be kept at rest on the stone. The tool should be held at the same height on the stone while being ground, if this be not attended to more than one facet will be produced; for the same reason the tool must be held at the same inclination during the whole operation of grinding. The stone is sometimes turned from the operator for convenience when grinding tools of peculiar forms; this is the case frequently when grinding the sides or edges of rectilineal tools, and occasionally in grinding pointed tools. When the edge of a tool has to be finished on the oil-stone, the angle of the edge given by the grindstone is less than in the finished tool; this defect in metal

and hard material tools is about 2°, the two facets thus given are distinguished with difficulty; in tools for soft materials the difference is 10°, and the facets are very distinct.

376. In BORING TOOLS, as the velocity is slower the angles are more obtuse than in turning tools, and in boring metals oil or water is more necessary with the lower than with the higher velocity. In boring holes for a screw to fasten two pieces of wood together, the screw should not be tight in the upper piece. In boring bolt-holes in metal the holes are made slightly larger than the bolt, this excess is technically termed *drift;* rivet-holes are made generally $\frac{1}{32}$ inch to $\frac{1}{16}$ inch larger than the nominal size, to allow the rivet to pass when red-hot. Thin plates are more readily punched than drilled, but holes of diameter less than the thickness of the plate must be drilled; machine punches and hand punches up to half an inch are made solid for iron unless very thin, hand punches exceeding $\frac{1}{4}$-inch diameter should be hollow. The best mode of punching a hole by hand is: firstly, to place the sheet to be punched on an anvil or other hard surface, and give the punch two or three smart blows, then remove the work to a sheet of lead, when a smart blow will drive out the piece hardened by the first operation; the surface of a punch should be kept flat and its edges sharp.

377. WIRE NIPPERS have edges which meet, and they do not cut keenly like shears or scissors, the best angle for the cutting edges is 30° to 40°; they should not be used for hard wire, nor wriggled while in the wire, as the edges are thereby notched. If they do not readily cut they may be applied a second time to cut a notch at right angles to the first one but in the same plane; the nose of the pliers and not the blades should be used to break the wire when not cut through. A less common kind of wire nippers than that described above has edges which pass each other like metal shears, and bevelled to 90°; these are better suited to telegraph purposes, being less liable to be injured by unskilful use. For office use and for cutting copper wires small pliers are suitable, but for line work, large (about 10-inch) cutting and holding pliers are necessary.

378. The pitch of a saw is the inclination of the front face of the tooth, or that surface up which the sawdust ascends; when the teeth are upright they are said to have no pitch; the degree of coarseness refers to the number of teeth to the inch. The generic angle for saw teeth is 60°, but with the same angle the pitch may be varied, as also the form of the teeth, as they may be deep or flat and far apart; as the teeth are formed alike, the angles of the points of the teeth are equal to the angles of the furrows. As in cutting tools, the angles of saw teeth are, as a rule, more acute the softer the material to be cut; saws for metal

have usually upright shallow obtuse teeth. Saws, as a rule, and metal saws invariably, should be lubricated with tallow or oil. A bar being sawn across should not be supported at two points, one on each side of the saw cut, as in this case pressure on the saw closes the cleft on the saw—the bar should be supported on one side only. Wood saws have the teeth bent alternately to one side and the other, this is termed the *set* of the saw; it widens the cleft and causes the saw to work freely. Saws are sharpened with a triangular file, and set either with a hammer or a tool with a slit in it to hold the saw tooth and bend it. Some wood saws have the edges of the teeth sharp, and present surfaces oblique to the flat surfaces of the saw blade. Saw blades are differently mounted, thus the rip saw has simply a handle, the tenon saw has a brass back to give stiffness, and there are different kinds of frame saws; metal saws have thin blades, and are stiffened by backs of brass like the tenon saw. Stone saws for such stones as marble have no teeth, sand and water drops into the cleft, and the stone is ground through. For cutting off cable guards flush, as in splicing, the metal saw should be used; the file is generally used for cutting wire, but it might in many instances be superseded by the saw with advantage.

379. Abrading tools are termed *files* when they are double cut —*i.e.*, the furrows and ridges are in two sets crossing each other, when single cut they are termed *floats*, and when the roughened surface is not produced by lines but by points, *rasps;* floats and rasps are almost exclusively used for woods and soft materials, but floats are used for cleaning metals for soldering. Ordinary files are: Lancashire of four degrees of fineness—viz., rough, bastard, smooth, and superfine; and Sheffield of four degrees—viz., rough, bastard, second cut, and smooth; rasps and floats are simply coarse or fine. In all these tools the fineness of each kind is not fixed but varies with the length, long tools of each kind being coarser than shorter ones of the same kind. Files are made of different cross sections, the commonest being termed triangular, half-round, and round; a kind having a T-shaped section is very acute on the edge, and is termed a knife file, these files are 2 to 7 inches long, and may be used with advantage for cutting wires instead of the triangular file. Floats and rasps are most commonly flat or half-round in section; tools termed half-round are not semi-circular in section, they are usually a much flatter curve. Sometimes an edge of a file is left uncut to rest against a guide or to allow of the file being used conveniently under certain conditions, such an edge is termed a *safe edge*. Files are never lubricated, if greased they do not cut; a worn file which cuts badly cold, cuts much better

when heated by a few seconds use. A flat float is used for cleaning wires to be soldered. Saws and files are driven in rhythmical strokes, they cut only when moving forward; during this movement in working metals considerable pressure is used: in all cases pressure is exerted according to the hardness, brittleness, or other mechanical qualities of the material operated upon, and in this part of the stroke the tool should be driven steadily in a right line, not tilted or rocked, and the pressure should be even and sustained. In drawing the tool back no pressure should be exerted, as it wears down the teeth without causing it to cut, but the tool should not be raised from the contact with the work; the backward movement requiring less exertion is performed quicker than the forward one.

380. The temper of axes, mortise chisels, and files may generally be taken down with advantage, as they are often so hard as to be unnecessarily brittle; if the edge of an axe or chisel be bent it may be readily repaired, but if chipped it is rendered useless. Both forged and rolled iron have usually a hard skin; before applying expensive tools (as in screw cutting) to such metal it is advisable to remove the hard external metal.

381. In the axe, hammer, mallet, and all tools required to act by percussion, the handle should be light in order that the centre of percussion may be as near as possible to the centre of the head. It is usually stated that the centre of percussion of the axe should be directly over and in the plane of the cutting edge, but as the blade is symmetrical about this plane this condition is always fulfilled. Adzes, phaoras, and pickaxes have bent blades in order that the edge may move in the path described by the centre of percussion. Hammers, picks, and phaoras should have strong sockets 3 or 4 inches deep, and almost cylindrical, in order that if the handle be accidentally broken it may be readily replaced by the user; some axe handles are of so complex a shape that, if broken, they can only be replaced by highly skilled workmen.

382. The strain on a wire can only be correctly ascertained in practice by means of a spring dynamometer similar to the spring balances used for weighing; this instrument should always be used for measuring the strain on important spans, as river crossings, where it is desirable to load the wire with its full working load to obtain the minimum dip. In straining up ordinary spans the workmen trust to the eye alone to obtain the correct dip, and they have one or two rough geometrical methods of measuring with the eye, but such methods are of little use; the more general use of the dynamometer would greatly reduce accidents from breakage of the wire, and greatly improve the mechanical condition of the lines in a most important particular.

Dynamometers of the kind alluded to are cheap, light, and efficient—their general use would promote economy; the dynamometer may be permanently fixed to the running block, or a lighter instrument may be applied to the tackle fall and its indications multiplied by the multiplying power of the tackle. Another mode of measuring the tension on a wire is by taking its inclination at the insulator with a clinometer, and from this and the dip, calculating the tension approximately (Paragraphs 175 and 193). This mode is very tedious, inexact, and unsatisfactory, compared with direct measurement of the strain with a dynamometer; the clinometer is the more expensive instrument, more difficult to use, and it is useless to uninstructed persons, who would find no difficulty in using a dynamometer. With the dynamometer and clinometer the dip may be readily measured (Paragraph 193); when the distance between the supports and the dip can be measured, as on ordinary land lines over level ground, the tension can be calculated (Paragraph 437). Wire cannot be strained fully unless the tension be measured, for if this be attempted the commonest result is, the wire being loaded beyond its proof load fails within a few weeks, generally during a strong breeze. The dip of an ordinary span may be measured directly with a tape or a light pole; this is sometimes done to check the tension. To ascertain if a mast is truly vertical and generally to test vertical lines and surfaces, a plumb rule is used; this consists of a board fitted with a plummet, one edge of the board is cut parallel to a line marked on the board, this true edge being placed against the mast or other body, the plumb line coincides with the ruled line if the surface tested is vertical. A mast cannot be proved vertical by a line let fall from its top; a long line is moved even by a very light breeze. In erecting iron masts in segments the upper surfaces of the segments successively erected are tried over with a spirit level. The spirit level is of general use to test if surfaces be horizontal. For measuring the angles of slopes, as in earthwork and masonry, an instrument on the same principle as the plumb rule is used; one surface or line on which being placed truly vertical or horizontal by means of a plumb line or spirit level, a second surface of the instrument gives the desired slope. For slight inclinations from the vertical the plumb rule is used, additional lines being ruled on it to give the slopes required. The slope of earthwork for telegraph structures is not usually measured by instruments, it being small in extent, and not required to be very accurate in figure. For marking out and testing horizontal lines, as in marking foundation pits and testing the bed joints in masonry, the cord is used; it is merely a stout string fixed by pegs at its extremities. A chalked string is used to mark straight

lines on materials, as logs, planks, sheet iron, &c. When a great many precisely similar operations have to be performed, as in fitting brackets to poles, digging holes, &c., a number of simple gauges should be made of sheet metal, plank, wire, string, or other material, and served out to each workman for his use; this plan is very economical, particularly when the workmen are not used to the particular work. For measuring the sizes of wires a plate iron or steel gauge is used, or better, a gauge formed of two straight edges placed in contact at one end and separated by a small interval at the other; the wire is gauged by being slipped between the straight edges—its size is then read off. There are several more accurate gauges formed of a system of levers; these are delicate, and applicable where great accuracy is required—they are not in common use. The ordinary plate gauge gauges sheet metal as well as wire, and the thicknesses of metal plates are distinguished by the same systems of numbers as wire. Ordinary measuring rules for use in hot climates are probably best made of metal; iron and steel rust readily during the rainy season, and should therefore be avoided—boxwood rules warp.

383. For holding and bending wire, and twisting wires together in making joints several ingenious tools are in use. The principal of these are—*eye-bolts,* for bending and generally manipulating thick wires; *joint levers, joint holders,* and *joint hooks,* for making twisted joints and holding the wires while joining them; *serving mallets,* for serving with thin wire; and *claws, tongs,* and *vices,* for attaching straining tackle to wires. The best form of eye-bolt is that shewn in fig. 69. It is made of

Fig. 69.

a piece of flat steel about a quarter of an inch or rather less in thickness, an inch to an inch and a half wide, and about a foot long; the holes 1 2, and the slots 3 4, are used to hold and bend the wire—they have rounded edges, and the diameter of each hole and width of each slot is suited to the diameter of the wire they are intended to hold. The eye-bolt figured, having four holes and four slots, is adapted to four sizes of wire; but these sizes should not be consecutive, as a single slot and hole is sufficient for several sizes if consecutive—the slots should be long enough to hold safely two wires at a time. An instrument for holding wires while making a joint, termed a *Britannia joint holder,* is in use in India, but not in general use in practice, as it is a very special tool and somewhat heavy; wires may be held by a slit of the eye-bolt or a small hand vice. Twisted joints are made by holding the crossed wires in a hand vice, in a clip fitted in a handle and tightened by a thumbscrew, or, if thin copper wires by a pair of

pliers, and twisting them by hand or with the eye-bolt; or a special tool, termed a joint lever or twisting apparatus, is used. A very good joint may be made by holding the crossed wire in a hand vice, screw clip, or eye-bolt, and twisting the ends with the hand or eye-bolt, the latter makes the closer joint. In twisting wires with the eye-bolt the wire is passed through the hole or eye, and bent round, as shewn in section, fig. 70: the bolt forms a lever to twist the wire; by bending the wire over the bolt at *d* it is kept tight. In bending or twisting thick wires by hand, 1 to 2 feet of wire must be allowed at each end to hold by and give a sufficient leverage. For serving with thin wire, as in making Britannia joints, a serving mallet may be used with advantage; the work can be done quicker, and the wire is laid on tighter and more evenly, than when served by the unassisted hand; joints made with the mallet may be shorter, and they never fail, as hand-made joints occasionally do. The handle of the mallet should be about 6 inches long; the head should fit easily over the joint to be made; the end of the mallet handle has a hole in it. To use the mallet, one end of the thin wire is passed through the hole in the mallet handle, once or twice round the handle, and round the wires to be served (fig. 71). The thumb is placed over the hole to keep the wire tight if necessary, and the mallet is turned round in the usual way. A hook is used in England for turning the ends of the line wire in finishing Britannia joints, but it is not necessary, as the wire is held sufficiently well by the binding wire. For holding the wire while straining it several instruments are used; the commonest is the *devil's claws*, and another instrument on the same principle, consisting of a piece of metal of a curved shape furnished with eccentrics, between which the wire is held. Half a dozen turns of thin wire put on tightly with a mallet will hold a wire while being strained; a rough loop for the tackle hook is made of a short piece of thick wire, which is then bound to the line wire. Rope stoppers are described and their advantages stated in Paragraph 370. They are generally used in India in preference to other contrivances; they are best suited to thick wires, and should always be preferred for considerable

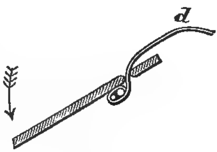


Fig. 70.

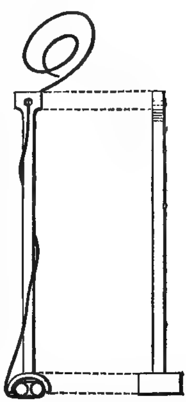


Fig. 71.

loads, as in straining up very long spans. A kind of clip or vice with a thumbscrew is used in France; this principle was tried in India for some time, but is no longer in use.

384. Screw-drivers, unless required to be very portable, should be large, a foot to 18 inches long; a screw-driver fitted in a brace is the least likely to injure screw-heads. For turning nuts adjustable spanners are best, but if a large number be required for a short time only, fixed steel spanners are more economical. A tool termed *gas tongs*, commonly used for gas pipes, is used in England; it is very useful for holding bolts, and removing them from wooden posts when rusted in; a tool on the same principle is used for screwing in screw-piles. The jaws of vices and adjustable spanners should not be screwed together, as it injures the teeth.

385. For reaching the tops of posts, ladders and contrivances to facilitate climbing are used; for extensive repairs and construction work ladders are used; the other contrivances are reserved for exceptional cases, to repair accidental damage, and for reaching the tops of masts too high to admit of ladders being used. Ladders should, as a rule, be made or purchased where required rather than transported long distances, particularly if bamboo or other light strong wood is procurable on the spot; if the wood has to be reduced in girth, straight grained light wood should be chosen, and it should be split rather than sawn. The best shaped ladder is one much narrower at the top than the bottom, if the posts have brackets the sides of the ladder may be joined at the top, so that the whole form a triangle; if the ladder has to rest against the post a sufficient opening should be allowed for the top rung to rest against the post; the object of having the ladder made wide at the bottom is to steady it and remove the necessity for a second man to hold it while in use; the ladder is not sensibly heavier than if its sides were parallel, it requires somewhat more skill to make, but if it can be made triangular it is much stiffer and stronger than a ladder almost or quite rectangular. The climbing iron is a steel or iron rod of the shape shewn in fig. 72; the waist of the foot is placed in B, and the branches A, C are furnished with straps to strap the instrument to the leg, the shorter arm A being placed on the inner side of the leg. One of these instruments being strapped to each leg the wearer is enabled to climb a wooden post by sticking the points into the post, these instrument cannot of course be used for climbing metal posts. In climbing smooth posts of either metal or wood, much assistance is afforded by an endless band, which may be made of webbing or of stout rope, canvas, or other suitable material; this is

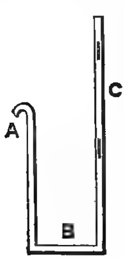


Fig. 72.

long enough (double) to rather more than half encircle the post, the two feet are placed inside the band, which passes over the instep and under the waist of each foot; in climbing the band passes tightly half round the post between the feet and gives a firm hold on the post, preventing the climber from slipping down. If the climber is required to use both hands he should have a band passed loosely round the waist and round the post, this he can lean against whilst working. In replacing wires on tall compound timber masts, it is a common practice to lower the topmast; this being tedious and expensive, the topmast should be climbed, but the climber should always have a band passed under his arms and round the mast, both to assist him, and as a precaution in case of slipping or giddiness; wires may readily be placed on masts 100 feet high by these means, the man climbing perhaps 40 feet above the trees of the standing mast. A contrivance used in Paris for washing down the fronts of high houses is well suited for use where long ladders cannot be obtained, or where their transport is inadmissible; a rope is knotted every 1½ foot or 2 feet, and suspended from the top of the building, the workman has each foot in a loop strapped firmly to each leg up to the knee, each loop has a large hook of suitable shape for putting round the rope over one of the knots; the man climbs the rope by shifting the hooks alternately to alternate knots, resting on one foot while he takes the pressure off the other. When working the hooks of the feet slings are both together on the same knot, and the workman sits on a board slung also by a hook placed over a higher knot; the man cannot fall, as he is always held by one leg, and he can move up and down the rope with greater facility than might be supposed. For painting high masts, and in general for telegraph work, when climbing has to be done only occasionally, this contrivance would prove very useful. A wire rope with projections would serve as a ladder for light masts, be cheaper, lighter, and less likely to be climbed by unauthorised persons than the ordinary fixed ladder.

386. To apply paint and varnish, a soft clean brush should be used, thin coats should be laid on, each coat being allowed to dry before covering it with another; as there is a tendency for the liquid to accumulate on edges and in angles, it should be laid on thinner at these places. A coating of thin size is sometimes used over porous wood to prevent absorption of the paint or varnish; when the object is to preserve the wood, several coats of linseed oil should be used; the application of size saves paint, but renders the painting much less effective as a preservative. French polishing is very simple, the polish is simply put on in thin coats with a pad made of cotton wool, wrapped in a

piece of soft linen or cotton cloth; or several coats are put on, the surface is then smoothed with fine glass paper, more polish is put on, then a mixture of polish and spirit, and ultimately, spirit alone, so that all the marks of the rag are removed and the surface is left quite smooth; a very little linseed oil on the pad makes it work easier. Lacker is a varnish for metal, generally brass, it may be applied cold, but if the metal be warmed below 212° F. the surface is more brilliant and the lacker less likely to chip off. Varnishes and paint put on in thick layers are not so durable as when put on thinly, and it is necessary to durability that each coat dry before another is applied. Varnishes are generally purchased ready for use, the following receipts may however be useful. The simplest and best French polish and lacker are as follows:—French polish, 1½ lb. shellac, 1 gallon spirit, dissolve without heat; lacker for brass, ½ lb. best shellac, 1 gallon spirit, dissolve by continuous agitation for five or six hours without heat, let it settle, and pour off the clear liquid; the colours used are turmeric, gamboge, and dragon's blood. Turpentine varnish for indoor work, 4 lbs. resin, 1 gallon oil of turpentine, with sufficient heat for solution. Crystal varnish for paper, 2 lbs. mastic or damar, 1 gallon turpentine, dissolve without heat; or, Canada balsam thinned with turpentine. Sealing wax varnish, 2½ lbs. good red sealing wax, 1½ lb. shellac, 1 gallon spirit.

Section III.—*Soldering.*

387. When two pieces of metal are joined together, the solder appears to combine with the metals superficially to form a thin coating of alloy, the altered surfaces being held together by the solder so as to form one piece; it is hence essential to success in soldering—*firstly*, that the metals be chemically clean and protected from oxidation by a flux while heated; *secondly*, that they be raised to a temperature sufficiently high for the combination with the solder to take place: fulfilment of the first condition is essential to adhesion, of the second to strength of the adhesion. The flux employed may act merely as a varnish excluding the air while the metal is heated, or it may also act as a deoxidising agent acting on the metal to produce chemically clean surfaces; the operation of soldering is rendered easier by employing fluxes of the second class rather than the first—*e. g.*, if resin be used as a flux the surfaces must be perfectly clean, but if sulphate of zinc be used there does not exist such strict necessity, therefore it is much easier to obtain good results with the latter flux than the former. Solders are more fusible than the metals they are intended to unite, so that

with ordinary care there is no risk of melting the metal with the solder; but the solder should approach as nearly as possible in mechanical properties, as hardness, malleability, &c., to the metal to be joined, and if regard be paid to appearance the colours of metal and solder should agree. If the metal and solder approach nearly in mechanical properties, the joint is almost equal in strength to the metal it unites, and may be hammered and bent almost as freely as if homogeneous; but if the solder and metal joined differ widely in malleability, hardness, and other mechanical properties, the joint is readily opened by bending the metal or by striking it. Soldered joints in which the mechanical properties of the solder and of the metal joined are very different, are therefore only applicable when the surrounding metal is so thin as to yield with the joint, when the work cannot be bent, or when the solder is employed for other purposes than strength bending wire or other appliance being applied to prevent relative motion of the pieces at the joint. Solders with the above exceptions are therefore usually made of the metals they are intended to join with a small proportion of more fusible metal to increase their fusibility. Examples are furnished by lead or pewter united by soft solder, and copper or brass united by spelter solder; in these cases the joint is nearly as tough as the metal joined, and may be bent and hammered; but if iron or brass (excepting as thin sheets) be united by soft solder, it may be opened by a blow. The various kinds of wire joint with but few exceptions, as in the case of very thin wires, depend on the twisting or bending for their strength; they are not really solder joints, the soldering merely makes the electrical connection, for if the binding or twisting be not sufficient to prevent movement independently of the solder, the solder will crack. The joints should be close, or the solder instead of being absorbed by capillary attraction when in the fluid state, will fall out; and the pieces joined should be kept motionless and pressed together while the solder solidifies. Most kinds of solder attack or gnaw more or less the metal joined, and sometimes, as in the copper wire for cables and delicate instruments, it is necessary to avoid this by using silver solder. To prevent this gnawing of the metal by solder in some measure, an unnecessarily high temperature and continued exposure to heat should be avoided. The manner of applying heat is varied according to the size of the objects, the fusibility, and general or local application of the solder.

388. Soldering is termed hard or soft; the hard solders do not fuse at a temperature below red heat, and are applicable therefore only to metals and alloys which will resist such high

temperature; soft solders melt at a much lower temperature, and are applicable to all metals, their composition being varied. Hard solders are finely divided for convenience of application, those generally used are *soft spelter solder* for common brasswork, 1 part copper, 1 zinc; *hard spelter solder* used for iron, 2 copper, 1 zinc. Solder used for steel, 19 silver, 3 copper, 1 zinc; for fine brasswork, 1 silver, 8 copper, 8 zinc; copper in shreds is sometimes used for iron; *hard silver solder*, 4 silver, 1 copper; *soft silver solder*, 2 silver, 1 brass wire; *gold solder*, 24 gold, 2 silver, 1 copper. Spelter solders are used for iron, brass, copper, and gun-metal generally. The zinc in these solders acts as a flux and burns when the solder melts, thereby indicating completion of the joint. Silver solders are used for fine work in iron, steel, silver, common gold, German silver, brass, copper, and generally when greater neatness is necessary than can be attained with spelter solder; being fusible compared with other hard solders, and not eating away the metal joined, they are used for joining copper wires where it is very important the electrical conductivity should be altered as little as possible, and it is undesirable to have an additional thickness at the joint; the individual copper wires in cable cores are joined with this solder by scarfed joints. The soft solders generally used are the following:—*Coarse tin solder*, 1 part tin, from 2 to 3 parts lead; *ordinary* or *common tin solder*, 1 tin, 1 lead; and *fine tin solder*, 2 parts tin and 1 part lead. The last is commonly used for line wires, and is the best for the purpose; the common and coarse solders are also used, but they have higher melting points, are weaker, and more readily oxidise; the only advantage of their employment is the difference in cost. For soldering pewter and lead it is advisable to use a greater proportion of lead, to approximate the mechanical properties of the solder to those of the metal to be joined; 1 part tin 25 parts lead melts at 558° F.; but to render the alloy more fusible bismuth is added; bismuth fuses at 398° F. (Pouillet); one author states it melts at 480° F., this is evidently a mistake. Pewterers' soft solder is composed of 2 parts bismuth, 4 lead, 3 tin; pewterers' common solder, 1 bismuth, 1 lead, 2 tin; 4 lead, 4 tin, 8 bismuth melts at 320° F.; 3 lead, 5 tin, 8 bismuth at 202° F.; the addition of mercury causes the alloy to melt at a still lower temperature. The more fusible solders are useful for soldering gutta-percha covered wires, thin foils, and leaden tubes containing covered wires; they are of limited application. There is much disagreement between authors concerning the melting points of solders. The following melting points are given on the authority of Tomlinson:—

Tin.	Lead.	Melting Point F.	Tin.	Lead.	Melting Point F.
1	25	558°	3	2	334°
1	10	541°	2	1	340°
1	5	511°	3	1	356°
1	3	482°	4	1	365°
1	2	441°	5	1	378°
1	1	370°	6	1	381°

The tenacity of fine tin solder is about 7500 lbs. per square inch.

389. THE SOURCES OF HEAT generally used for hard soldering are—the naked fire, furnaces, muffle, and blowpipe; if the work be placed in contact with the fuel the presence of sulphur should be avoided, by using charcoal or coke rather than coal. Ordinarily the sources of heat employed for hard soldering are seldom used for soft soldering, but the naked fire is sometimes used for large work. Articles to be soft-soldered may be dipped into melted solder, or the solder may be poured over the joint in sufficient quantity to heat the metal to the temperature necessary to adhesion; this practice is however a bad one, for if the solder be kept melted it undergoes a change which destroys its useful properties, it becomes porous and brittle, and will no longer adhere. This practice has not the advantages sometimes claimed for it; Britannia joints dipped, soaked, and moved about in melted solder do not absorb the solder, as is generally supposed; on sawing open a number of joints made in this manner with every precaution, in no case had the solder penetrated the joint as was expected, and although this may occur in some cases, these are exceptional. The most useful source of heat is a piece of untinned iron, of a shape and weight suited to the work; tin-plate workers in India use iron bolts for all work. A convenient form of heater is a piece of flat bar iron, the work is held on the hot iron until the solder runs. For soldering joints in line wires and for all thick work the iron soldering bolt is probably the most convenient source of heat; the shape of the heater should be such as to expose the minimum of radiating surface, and admit of the heat being concentrated on the joint; the best form for joining line wires is probably an ellipsoid with a groove into which the joint can be laid; the groove should be slightly deeper in the centre than at the edges, in order that the solder may not run out when melted, it should be the length of the joint to be made, deep enough to receive the joint, parallel with the longer axis of the ellipsoid, and the handle should be fixed at right angles to the groove. A heater containing 1½ to 2 lbs. of iron will solder No. 1 wire readily. The specific heat of iron being ·1098 and that of copper only ·0949, iron takes longer to heat

and cool; it should not be used red hot, and should be wiped on removal from the fire. The copper bit, a piece of tinned copper of suitable shape and weight fixed to a handle, is the best source of heat for thin wires and sheets and small work; it is universally used in Great Britain by tinplate workers. Being tinned melted solder will adhere to it, hence it may be used to pick up and apply the solder; the specific heat of copper being low it is readily heated, when the work is small this is a convenience and a source of economy in fuel, but for heavy work, as joints in thick wires, the copper bit is quite unsuitable. The iron bolt is cheaper and does not burn away; copper absorbs the solder, rapidly wastes, does not keep hot, and the tin is readily burnt off; heavy work cannot be thoroughly heated by a copper bit, and there is great danger of a merely superficial and deceptive coating of solder being laid over the joint. Copper bolts should not weigh much more than half a pound, if greater heat be required than this will furnish the iron bolt should be preferred. The blowpipe flame, a spirit lamp, or a torch made of three or four dozen thin rushes with a slight coating of tallow, are sometimes used, but the iron and copper bolts are employed more generally. For repairing line wires a small sheet copper box with a handle is used in England, a groove in its upper surface receives the joint to be heated, the fuel employed is composed of coke or charcoal, mixed with a chlorate, nitrate, or other salt supplying oxygen readily; the fuel being ignited the box is used as an ordinary soldering bolt. This contrivance is very portable and exceedingly useful for repairs after interruption.

390. Fluxes.—The flux most generally used is chloride of zinc in strong solution; it may be made by saturating a mixture of equal parts hydrochloric acid and water with metallic zinc, it is applicable to all metals, and gives the best results without that strict necessity for clean surfaces necessary when most other fluxes are used; it is therefore easier to solder with than other fluxes, and as zinc is a metal difficult to solder well, this flux should be generally used for zinc. Chloride of zinc is generally used for soldering line wires, the only objection to its use is that it leaves a metallic salt on the work which may cause oxidation; joints made with this flux should be carefully washed with solution of common soda, or if this be not procurable with water. Chloride of ammonium, termed sometimes muriate of ammonia, and in commerce sal ammoniac, is a flux next in utility to chloride of zinc; it is used mostly for iron cast and wrought, and also for copper and its alloys; it is often used with resin, and sometimes with chloride of zinc, as bichloride of zinc and ammonium; it is used alone for soldering zinc, but is inferior to

chloride of zinc for this purpose. Like chloride of zinc it assists in cleaning the surfaces to be joined. Resin is a flux very commonly employed, it does not act on the metals as the fluxes mentioned above; hence when this or any of the following fluxes are used the strictest necessity exists for clean surfaces; for this reason difficulty is often experienced in soldering untinned iron with this flux. It is generally used for tinned iron, and for making joints in cable cores and resistance-box connections, in preference to the salts of zinc and ammonium, the use of which might be highly injurious from the possibility of a small quantity of the salt being left on the joint to subsequently corrode it. Resin is used for tin alloys, and mixed with oil it is used for lead and tin pipes; tallow is used for lead; Venice turpentine and sweet oil are also used for fusible metals and alloys, as lead, pewter, &c.

391. Soft soldering, from the low temperature of fusion of the solders, is applicable to almost all metals: the operation is very simple; the surfaces to be joined should be cleaned, lead and pewter are generally scraped, iron and copper are cleaned with emery paper or acid, or scraped with a knife to bright surfaces. Tinplate and thin metals usually have a little flux placed on them and the solder and heat applied at once, but thicker masses of untinned metal should be tinned by the application of a little flux and dipping in melted solder. The latter operation is particularly necessary in the case of iron, as the solder does not always adhere well; it should always be applied to line wires before binding or twisting them together, and to binding wires if not tinned; the tinning should extend over the whole surface denuded of zinc when making joints in galvanised wire, to prevent subsequent oxidation of the iron. Soft solder joints are merely pressed together with a little solder and allowed to cool at rest, the superfluous solder is pressed out, and the operation somewhat resembles gluing. To join line wires the joint is placed in the groove of the soldering bolt, covered with a little flux, and the solder being placed in the groove, it rises by capillary attraction and covers the joint; the solder should not be placed on the joint. With thin wires and the copper bolt a little solder may be applied by the point of the bolt. In soldering a long joint or seam by moving the bolt, care should be taken to move it slowly; by moving it too quickly a weak joint is made. Copper alloys dissolve in the solder and require care to prevent the edges of the metal being eaten away. Large objects may be heated and the solder and flux applied to them while hot—a charcoal fire is the most convenient for this purpose.

392. Brazing is generally done in an open fire urged by

bellows; when the blowpipe is used the work is placed on charcoal or cinders, which may be held in a spoon, or, better still, in a piece of pumice-stone hollowed for the purpose; the blowpipe is commonly used with a spirit lamp for small work. The flux generally used in hard soldering is borax, and it is better to fuse the borax before use, as otherwise it is apt by crepitating to remove the solder. The pieces to be joined should be fixed together as they are required to be joined, they are commonly tied with thin iron wire; the granulated solder mixed with powdered flux being spread on the joint, the heat is raised gradually to desiccate the flux, it should be uniform over the whole joint, and when the solder has run or *flushed* the work is removed from the fire. Iron being less liable to fuse than most other metals requires less caution in heating it; but it is apt to scale, and is often covered with loam to protect it while being heated.

Section IV.—*Surveying, Drawing, &c.*

393. Surveying in its extended sense includes levelling, in a limited sense levelling is excluded. The object of surveying in its limited sense is to determine the relative positions of objects, the shapes and areas of portions of the earth's surface, and to define on the ground and represent on paper lines and areas. The data obtained by surveying are considered relative to a horizontal surface and represented on paper by a *plan;* generally in engineering, and invariably in the case of telegraph surveying, the earth's surface may be considered plane. The points chosen between which lines are drawn are termed *stations,* the lines joining these are termed *station lines;* the stations selected in the first instance whose relative positions are first determined are called *principal stations,* and the lines between them *base lines* or *principal station lines.* The principal stations are those prominent points, permanent or temporary, which are first selected, and to which the positions of other points, termed secondary stations, are determined and represented, and ultimately details filled in. Levelling determines and defines the relative elevations of the ground and of buildings and other objects; the data obtained are represented on paper by a *section,* and they are referred to a vertical plane. As relative results are required, a point has to be selected to the elevation of which the other elevations to be determined may, at least in the first instance, be referred; such point is termed a *datum point,* subordinate datum points are called *bench marks.* For purposes of verification a *datum fixed point* is chosen, this is usually a point on a building chosen so that it is permanent and readily recog-

nised. Stout stakes are used as datum points and bench marks; they should be driven nearly to the head, and be placed in situations where they are not liable to be disturbed.

394. The MEASURES OF LENGTH employed in England in engineering are: the yard, the foot, and the inch—the inch is divided into eighths, twelfths, or decimals; the fathom of 2 yards, the chain of 66 feet, divided into 4 poles and 100 links; the statute mile of 1760 yards, divided into 8 furlongs; the nautical mile-this is equal to one minute of latitude, and therefore varies in different latitudes, the value commonly assumed is one minute of longitude at the equator, about 6086 feet; this is also termed a knot, it is the unit used in cable work, and is sometimes divided into 10 cables, each subdivided into 100 fathoms, the fathom being about $\frac{1}{80}$ longer than the common fathom. The FRENCH UNIT OF LENGTH is the mètre, which is approximately one ten-millionth part of the distance between one of the poles and the equator of the earth, it is 3·2808693 feet or 39·37043 inches British measure; the mètre is divided and multiplied decimally, 1000 mètres = 1 kilomètre = 0·621383 of a statute mile. The BRITISH MEASURES OF AREA employed in engineering surveying are: the square foot of 144 square inches, the square yard of 9 square feet, the acre of 10 square chains, and the square mile; telegraph engineers have seldom to deal with areas, when they do the areas are small in extent. The measures of volume are: the cubic inch, the cubic foot of 1728 cubic inches, and the cubic yard of 27 cubic feet. The FRENCH MEASURES OF AREA are the square mètre = 10·7641 square feet, and the square millimètre = ·00155003 square inch; the measure of capacity is the cubic mètre = 35·3156 cubic feet.

395. In surveying a route for a telegraph line, whether it be a mere preliminary survey or actual setting out of the work, the engineer has occasion to use instruments for taking levels and making angular measurements; lines are sometimes marked out by the eye alone, rough geometrical method being employed to measure and subdivide angles; but as a general rule the use of instruments is either absolutely necessary to furnish the information required, as in measuring rivers, or highly conducive to economy by saving the time of the surveyor, rendering the work more accurate and the route shorter. Telegraph lines are generally erected along roads, railways, and other principal lines of communication, and the position of the structure is for the most part so far fixed that the requisite survey is of a simple kind; but surveys for unbridged river crossings, lines over hilly country, and over tracts untraversed by roads, &c., demand the employment of reliable instruments and methods, and generally when

accuracy is necessary exact and complete instruments are more satisfactory in use, save time, and lessen exposure of the men. A small theodolite is best adapted to these purposes; it may be used as a level for taking differences of level of river banks; long straight lines are ranged by first looking in one direction, then reversing the telescope and looking in the opposite direction. With a 6-inch theodolite a line may be ranged with an error not exceeding 3 inches per mile. For the details of a line as for dividing the angles, and marking the anchor holes for angle posts and masts, an ordinary magnetic compass with sights on a tripod, with a plummet hung from a point immediately under the axis of the needle, is a most convenient instrument; or a prismatic compass similarly fitted may be used, and is generally preferred. The plummet being brought immediately over the peg marking the position for a post, horizontal angles may be very readily measured; when a rough approximation only is required the compass may be held in the hand. The compass can be read to a quarter of a degree, and the limit of error is within half a degree for most of the measurements required in telegraph work, as the relative and not the absolute magnetic azimuths of objects are usually measured. The box sextant is not so well suited for general use in marking land lines as the prismatic compass, but it has many advantages under particular circumstances; it can be used for oblique and vertical angles, and with an artificial horizon for taking altitudes, it may be used in a boat while surveying rivers, it is much more accurate than the compass, and may be read by the vernier to one minute, and by estimation to half a minute. The telescope is an advantage in telegraph work, the lines ranged being usually long, but the box sextant is not usually used for lines longer than a mile. For ascertaining roughly differences of level between contiguous posts and over short distances generally, the best instrument is the level, fig. 73; it consists of a piece of glass in a metal frame of the shape figured, half the glass A is silvered, the other half B is unsilvered, a hair or wire is stretched between C and D. In use the instrument is held by the ring E, it then hangs vertically; it is held some distance from the face of the observer, who brings the image of his eye on the hair on the mirror, and at the same time reads off on the levelling staff through the plain glass with the same eye the point where the hair crosses the staff. To measure the differences of levels of posts a tape may be held against the

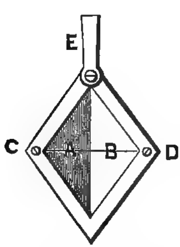


Fig. 73.

post, a temporary staff may be made, or a man may raise or lower a stick until he marks on the post the point where the hair crosses the post. The water level, consisting essentially of a tube bent twice at right angles, and containing fluid, usually coloured, may be used if greater accuracy be desired; the line of sight in this instrument is furnished by the surfaces of the fluid in the two legs, which are of glass, these surfaces being necessarily in the same horizontal plane. The theodolite may be used for levelling; it may either have its line of collimation set horizontal or at a known angle. Altitudes may be measured on land by the sextant, by using it to take angles of depression and elevation. The most accurate levelling instrument is the telescopic level, termed the spirit level, or level proper; it is not necessary to use this instrument, as the lines to be levelled are usually short, and the strictest accuracy is not necessary. The ordinary chain is usually replaced by a tape, which is much more portable; 66 feet is a convenient length, being $\frac{1}{80}$ of a mile. The chain is used by some, either the chain proper of 66 feet or one of 100 feet; it should measure the nominal length including the handles. A stout string or a wire, measured off by means of the tape and checked from time to time, is commonly employed in marking out lines; this should be an aliquot part of the standard distance from post to post, and should be marked at the half and quarter of its length. When measuring with the chain or string, the man in advance, termed *the leader*, walks in the line chosen, being directed either by a flag or mark in advance, or by the man following, termed the *follower;* at starting the leader is furnished with as many iron skewers or arrows as the measuring line is contained in the standard distance, and he sticks one of these in the ground to measure from; having walked from this point the length of the line, he faces the follower, the two men stretch the line, the follower by motions with his hand or by his voice directs the leader into the alignment, and makes a sign or says "mark," on which the leader sticks an arrow in the ground and proceeds, the follower takes up the first arrow and follows; when the arrows in the hands of the leader are exhausted, the distance between the point marked by the first arrow and that marked by the last is the standard distance between two posts; these points are marked by flags or pegs, the follower gives all the arrows but one to the leader, and they proceed as before. The number of arrows in the hand of the follower indicates the number of times the cord has been applied at any time, reckoning from the last peg or flag; generally in measuring with a chain, arrows are used in the manner described above; in measuring long lines

10 arrows are used, and the surveyor enters every length of 10 chains as measured. If the chain be used it is necessary to verify it, straighten any links accidentally bent, and keep the links free from earth. An opera glass or telescope is necessary in order to distinguish flags or pegs at considerable distances, and examine and range long lines; a single glass or telescope should be preferred to the binocular. The flags usually have sticks about 10 feet long shod with iron at one end, and having a small piece of thin coloured cloth at the other; to reduce the weight 6 feet poles are often used, and as many are required in setting out telegraph work, any cheap light rods readily procurable may be used instead of the iron-shod well-made sticks commonly used in engineering surveying. The colour seen at the greatest distance is white, red is easiest to distinguish from foliage and grass, but on railways the colours used for railway signals should be avoided; in open country, rods of light wood either white, or painted in alternate stripes white and black, serve instead of flags. White rather thick hollow bamboos form excellent marking rods, a small crowbar or khuntie may be used to make the holes and fix them in the ground. For ranging long lines, or when a high object has to be seen over, long poles may be used, placed vertical by a plumb line and kept so by stays; when accuracy is desired these are used for marking long station lines. For marking on the ground, pegs driven nearly to the head are used; cleft sticks with pieces of white paper in the clefts, technically termed *whites*, are useful to render pegs visible at a distance. Horizontal distance on a slight incline is measured with sufficient accuracy by being measured in steps; the measuring line is held to the ground at one end, the other end is raised until the cord is horizontal, a plumb line or stone let fall from the raised end marks a spot to which the ground end of the line must be transferred in continuing the measurement lower down the incline. When the incline is steep it may be measured in half or quarter chains at a time. Inclines may be measured by the clinometer, reference to a table will give the rise or fall, and the number of links and parts which must be subtracted from each chain to obtain the horizontal distance, the corrections can thus be made while measuring; a table of these corrections is usually engraved on clinometers and theodolites. In marking out, the pegs should be so placed as not to be disturbed during the progress of the work, in order to prevent or render evident departure from the original design. For measuring short distances a light rod may be used; this may be made on the ground, or one of the flag staves may be graduated. For sounding shallow rivers or pools a rod weighted at the lower end is the best instrument; when

too deep for this a chain is used for depths less than 100 feet, and a lead line for greater depths. The last consists of a piece of hard strong cord knotted at every fathom, having at one end a conical piece of lead, the lower part of which is hollow and contains tallow or other hard grease. The length of cord run out gives the depth, and the matter adherent to the greased surface shews the nature of the bottom. The permanent and temporary adjustments of the several optical instruments used in surveying are best learned by practice, aided by reference to books on the subject.

396. If ABC be a right-angled triangle the trigonometrical functions of the angle BAC (referred to as angle A for brevity) are defined as follows: $\frac{BC}{AC}$ is sine A; $\frac{AB}{AC}$ is cosine A; $\frac{BC}{AB}$ is tangent A; $\frac{AB}{BC}$ is cotangent A; $\frac{AC-AB}{AC}$ is versed sine A; and $\frac{AC-BC}{AC}$ is coversed sine A. The functions of an obtuse angle, CA$b = 180° -$ A, are defined as follows:—The line BA being produced in the direction Ab, AB and Ab lying in opposite directions from A have opposite signs; applying the lines bc, Ac, and Ab as the lines BC, AC, and AB are applied in the above definitions for the functions of the acute angle A, but using the opposite sign for the line Ab, the corresponding functions of the obtuse angle are obtained. In other words, the functions of the obtuse angle cAB are those of the acute angle cAb—*i. e.*, of the angle BAC with the sign of AB changed, therefore the functions of an obtuse angle $= 180° -$ A, with the exception of the versed sine, are numerically equal to the functions of A, but their signs are not necessarily the same. The relations between the corresponding functions of an obtuse angle and its supplement are as follows:—

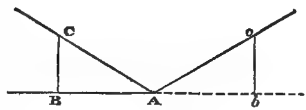


Fig. 74.

$$\begin{aligned}
\sin(180° - A) &= \sin A; \\
\cos(180° - A) &= -\cos A; \\
\text{versin}(180° - A) &= 1 + \cos A = 2 - \text{versin } A; \\
\text{coversin}(180° - A) &= \text{coversin } A; \\
\tan(180° - A) &= -\tan A; \\
\text{cotan}(180° - A) &= -\text{cotan } A; \\
\sec(180° - A) &= -\sec A; \\
\text{cosec}(180° - A) &= \text{cosec } A.
\end{aligned}$$

In short the sine and cosecant of an obtuse angle have the same sign as, and the cosine, tangent, cotangent, and secant, the

opposite sign to, the corresponding function of its supplementary acute angle. The elementary relations between the different functions of one angle are as follows :—

$$\sin A = \sqrt{1 - \cos^2 A} = \frac{\tan A}{\sec A} = \frac{1}{\operatorname{cosec} A};$$

$$\cos A = \sqrt{1 - \sin^2 A} = \frac{\operatorname{cotan} A}{\operatorname{cosec} A} = \frac{1}{\sec A};$$

$$\operatorname{versin} A = 1 - \operatorname{cosin} A;$$

$$\operatorname{coversin} A = 1 - \sin A;$$

$$\tan A = \frac{\sin A}{\cos A} = \frac{1}{\operatorname{cotan} A} = \sin A \cdot \sec A = \sqrt{\sec^2 A - 1};$$

$$\operatorname{cotan} A = \frac{\cos A}{\sin A} = \frac{1}{\tan A} = \cos A \cdot \operatorname{cosec} A = \sqrt{\operatorname{cosec}^2 A - 1};$$

$$\sec A = \frac{1}{\cos A} = \sqrt{1 + \tan^2 A};$$

$$\operatorname{cosec} A = \frac{1}{\sin A} = \sqrt{1 + \operatorname{cotan}^2 A}.$$

The elementary relations between the functions of an angle A and the angles 2A and $\frac{A}{2}$ are as follows :—

$$\sin A = 2 \sin\frac{A}{2} \cdot \cos\frac{A}{2} = \frac{2}{\operatorname{cotan}\frac{A}{2} + \tan\frac{A}{2}} = \sqrt{\frac{1 - \cos 2A}{2}};$$

$$\cos A = \cos^2\frac{A}{2} - \sin^2\frac{A}{2} = 1 - 2\sin^2\frac{A}{2} = 2\cos^2\frac{A}{2} - 1 =$$

$$\frac{\operatorname{cotan}\frac{A}{2} - \tan\frac{A}{2}}{\operatorname{cotan}\frac{A}{2} + \tan\frac{A}{2}} = \sqrt{\frac{1 + \cos 2A}{2}};$$

$$\tan A = \frac{2}{\operatorname{cotan}\frac{A}{2} - \tan\frac{A}{2}} = \sqrt{\frac{1 - \cos 2A}{1 + \cos 2A}} = \frac{\sin 2A}{1 + \cos 2A} = \frac{1 - \cos 2A}{\sin 2A}$$

The sum of the angles of a plane triangle is 180°—*i. e.*, equal to two right angles. The sides of a plane triangle are proportional to the sines of the angles opposite to them respectively. The square on the hypothenuse of a right-angled triangle is equal to the sum of the squares on the other two sides. In surveying, triangles having any angle less than 30°, or more than 150°, are termed *ill-conditioned*, and are avoided. The measurements of triangles may be checked by the following methods:—By measuring the three angles, their sum should be 180°; a tie line being drawn from one of the angles to a known point on the opposite side, test its agreement with the lengths of the sides, either by measurement on the plan or by calculation; when several triangles form together a polygon, the internal angles of this figure should equal twice as many right angles, minus four, as the figure has sides; in a network of triangles, lines which are common to two triangles may be calculated from two independent sets of data—the values so obtained should agree. If there be any unavoidable error in the angles (after allowing for spherical excess if necessary) it should be divided equally amongst the three angles. In the absence of an instrument for setting out right angles, lines may be marked at right angles to each other by setting out a triangle, having its sides so proportioned to each other that the triangle shall be right-angled; the simplest proportion is 3 : 4 : 5, the first and second terms representing the ratio between the sides containing the right angle.

397. Two methods are used in surveying with the chain—one is that by DISTANCES AND OFFSETS; this method is that employed as a rule for filling in details of surveys. It consists in measuring distances in a straight line, and measuring from this line the perpendicular distances of objects on each side of the line, these perpendicular measurements are termed *offsets;* in exceptional cases oblique offsets are used, being set out by angular measuring instruments. The lengths of the offsets, their distances apart measured on the station line, and the side, right or left, of that line on which they are drawn, being known, they may be represented on paper, and the relative positions of the objects to which the offsets are drawn are thus determined. Short offsets are commonly laid by the eye, and may be measured with an offset-staff, a light wooden pole ten links long, divided into links or feet; longer offsets are correctly set at right angles to the station line with the optical square, cross staff, a box sextant set to 90°, or other means, are measured by the chain, and are seldom made more than one chain in length when accuracy is desired. A plan of a telegraph line along a road, railway, or other line of communication may be taken by this method with sufficient accuracy

for practical purposes by entering the distance of each post from the road, railway, or canal, the distances between the posts, and the side of the road on which the line is situated, the magnitude of its angles, &c.; the offsets in this case need not be measured, they may be guessed in most cases with sufficient accuracy for use. The particulars of a survey by distances and offsets are entered in a *Field-book* in the following manner:—A line or column in the centre of the page represents the station line, distances measured on the station line are marked on this line, the lengths of offsets and objects to which they are drawn are entered on the proper side of the station line, small sketches are introduced to give full particulars, and a preliminary sketch is entered to shew the relative positions of the stations and the signs by which they are distinguished. In order that forward, backward, right and left, in the field-book may represent these directions on the ground, the pages are numbered from right to left, and written from bottom to top. The field book for a rough survey of a telegraph line has a central column representing the road, track, railway, or canal, and a column on each side to represent the line; the lengths of offsets are put on the proper side of the road column, and in the road column is put the distance between the telegraph posts; at angles the sign $\angle$ or ⦣ is written, shewing if the angle opens to or from the road, and the magnitude of the angle is stated, differences of level, height of road embankment, villages, obstructions, tall posts, trees, jungle, swamp, &c., are shewn by being written in words, numerical particulars as to distance from the line, &c., are entered approximately by guess; but at rivers, and wherever necessary, measurements may be made with any desired degree of care. By these means a sketch of the line may be prepared of great use in preparing estimates for repairs, exhibiting the position of the line relative to the road and other important objects, while for general purposes no greater expense need be incurred than the nature of the case demands; approximation is substituted for measurements, excepting in the case of the actual dimensions of the telegraph structure, or where the circumstances of the case demand a greater degree of accuracy than this method affords. The second method by which a chained survey may be conducted is by TRIANGLES, or by TRIANGLES AND DISTANCES AND OFFSETS conjointly; it is evident if a number of points be connected by lines forming a network of triangles, and these lines be measured, the relative positions of the points are determined, and may be represented on paper; for if the respective lengths of three sides of a triangle be determined, the angles may be calculated or correctly represented on paper. In surveying with the chain, when obstacles are met

with which cannot be chained over, a line passing through them can only be measured by chaining round them, or by laying down one or more triangles so connected as to afford data for calculating the required distance through the obstacle. The measuring of the sides of triangles is slow, and lines on the ground cannot be so accurately measured as angles, hence surveying with the chain is usually confined to details. SURVEYING BY ANGULAR MEASUREMENTS is carried out by the method of triangles; but as angles are measured as well as lines, few lines are measured, the lengths of the others being calculated. The commonest case is that in which one side and two angles of a triangle are measured, and the other two sides and one angle are either calculated or plotted from this data without calculation. This mode of surveying is more accurate than chain surveying, better adapted to large areas and long lines, is more expeditious, particularly in measuring across obstacles, as rivers, &c., and it is therefore used for the long lines and principal measurements in extensive surveys, the details being filled in by means of the chain, as already stated. The PLANE-TABLE is very useful for the limited surveys required in telegraph construction, such as in surveys of river banks, for cable huts and masts. This instrument consists of a drawing board fitted on a stand and furnished with a spirit level, a clamp and tangent screw, and a ruler with sights, termed the index. The plane-table is used to survey by angular measurements: a sheet of drawing paper is strained on the board, the board is placed horizontal, and the angles are marked in the field directly on the paper by means of the index.

398. THE OPERATION OF LEVELLING is exceedingly simple, and consists in making two or more observations (technically termed sights) with the levelling instrument at the same place or station; the levelling staff is placed upon a point, the level of which has been ascertained, or which is a datum point, and then upon another point the level of which it is desired to ascertain, the different readings shew the levels of the two points relative to each other, and to the datum point. When two sights only are taken from each station—viz., one with the staff on a point the level of which is known, and one on a point the level of which has to be ascertained, the former is termed the *back-sight* and the latter the *fore-sight;* when more than two sights are made from the same station the first is termed the *principal back-sight*, the last the *principal fore-sight*, and each successive sight is a fore-sight to that which was taken before, and becomes a back-sight to that taken after it, a back-sight being an observation of the staff on a point the level of which is known, a fore-sight being an observation of the staff on a point the level of which

has to be ascertained by comparison with the last back-sight. In levelling it is necessary to make a correction for the curvature of the earth and refraction when sights are taken over long distances, but the error may be neglected for sights over distances up to about 200 yards. The levelling required for telegraph purposes seldom need exceed this; and when this distance is exceeded, as in levelling between hills or across rivers, the strictest attainable accuracy is not usually required; the correction when necessary may be assumed to be on an average—

$$\cdot 56 \text{ (distance in miles)}^2;$$

this fraction to be subtracted from the reading. Observations to ascertain the heights of detached points are termed *flying levels*, such heights are written on the plan. Levelling by measuring angles of elevation and depression is used for taking flying levels, but is not sufficiently accurate for an extensive series of connected observations in which a high degree of accuracy is essential. A single line of soundings does not give sufficient information, two or more lines or a series of trial soundings are necessary; the latter are usually sufficient, but the former are desirable as admitting of the contour lines of the bottom being put in the plan. For engineering purposes the measurements should be taken in feet and tenths or inches, the depth of water on the plan may be marked in fathoms, but on the section feet and tenths or inches should be used exclusively. The direction of the current may be found by dropping a light body into the water from a boat, and taking the angle between the direction in which the body moves and a line ranged on shore. The velocity of the current is readily measured by observing the time taken by a floating body to traverse the distance between two stations a known distance apart; light sticks, weighted at one end, so as to float upright, are usually used as objects. As this method is a rough one, several trials should be made and the mean taken. Surveys for sea cables are made by nautical surveyors from ships despatched for the purpose; the positions of the ship when the soundings are taken are ascertained by the means usually employed for purposes of navigation. Levels and soundings are checked by going over them again, either partially or completely.

399. For ordinary purposes the only drawing instruments required are a good pair of compasses, spring bows for small circles and measurements, a scale preferably of metal, a graduated flat ruler for long lines, and a small divided set square for drawing and measuring offsets. The scale most useful is the sector; a 6-inch rectangular protractor having engraved on it scales of

inches and a scale of chords may be used—it is inferior in accuracy and usefulness to the sector, but for setting out angles it saves time. When much drawing has to be done, set squares, the T square, the parallel ruler, &c., save time, but they are neither portable nor essential; when great accuracy is desired in plotting surveys and in executing large drawings, beam compasses and the large accurately-divided circular or semi-circular protractor are necessary. Proportional compasses are used for copying on a reduced or enlarged scale. Straight lines are ruled with the bow or ruling-pen, measurements are pricked off with a pricker, consisting of a needle fixed in a handle. Where great accuracy is required it is better to draw in ink at once, but mechanical drawings are usually drawn in pencil first, and the pencil lines inked afterwards. The paper to receive mechanical and architectural drawings is generally damped, pasted on a drawing board, and allowed to dry for use; it shrinks in drying and forms a smooth surface to draw upon, but as when cut from the board it shrinks, this treatment is not suited to paper intended to receive surveyors' plans and sections. If a high degree of accuracy is necessary, paper to be mounted on cloth should be mounted before being drawn upon. Descriptions of and directions for using drawing instruments and scales may be obtained from any of the numerous works on the subject, as Mr. Heather's *Mathematical Instruments* in Weale's Series, Mr Burchett's *Practical Geometry*, &c. Before commencing to represent the particulars of a survey on paper, a scale should be drawn in order that it may shrink or expand with the paper; on sectional drawings the horizontal and vertical scales should be drawn at right angles to each other, in order that if the paper shrink unequally in its two dimensions the scales may shrink proportionately.

400. FOR PLANS the smallest scale which admits of roads and buildings being represented distinctly, is 6 inches to a mile, or $\frac{1}{10560}$; the nearest decimal scale to this is $\frac{1}{10000}$, or 6·336 inches to a mile. For representing telegraph lines on common roads and railroads the scale should not be less than 8 inches to a mile; $\frac{1}{2}$ an inch to the standard distance between contiguous posts is a good scale for such plans. For plans of river crossings and overhead town lines a scale of 100 feet to an inch, or $\frac{1}{1200}$, is suitable; but for intricate towns, and underground wires, a larger scale is necessary. The scale of ordnance plans of the most intricately built towns is 44 feet to an inch, or $\frac{1}{528}$. FOR SECTIONS two scales are almost invariably employed—viz., the scale for *horizontal distances*, which should as a rule agree with that of the plan, and the *scale for heights*, or *vertical scale*. As differences of elevation are as a rule much smaller than the horizontal

measurements, the scale of heights is usually greater than the horizontal scale in a proportion termed its *exaggeration;* this proportion varies from 6 or 7 to 16 or 18. For most telegraph sections a scale of 10 feet to an inch, or $\frac{1}{120}$, is suitable; with this and a horizontal scale of $\frac{1}{1200}$, the exaggeration is 10.

401. In geometrical drawing both lines and angles are more correctly drawn when of large size, and in applying the rules of practical geometry the diagrams should be as large as practicable —*e.g.*, in setting out a required angle, the scale of chords on the ordinary scales being small, if great accuracy be desired, instead of using one of these, as large a radius should be taken as the paper will allow, and this radius multiplied by twice the sine of half the required angle will be the chord required; the sine may be obtained from a table of sines. Similarly in drawing a perpendicular to a given line and other problems, if the radii or other lines used in the constructions be taken as long as practicable, greater accuracy may usually be attained than if rules, scales, and set squares be used; but to economise labour these several appliances are used, excepting when great accuracy is necessary. Lines are more accurately set out by beam compasses than by ordinary compasses. Under ordinary circumstances lines may be drawn with greater accuracy than angles, hence in plotting triangles, when great accuracy is required, the lengths of the sides are calculated and the triangle drawn with three given sides, thus avoiding the necessity for drawing the angles directly. Chained triangles are drawn by measuring off the three sides. The principal triangles in trigonometrical surveying, when great accuracy is desired, are usually drawn by calculating the sides; this plan is pursued in drawing great triangles, it is seldom necessary for telegraph surveys; when less accuracy is necessary the known side or sides are measured, and the angles are *protracted*—*i.e.*, drawn by means of a protractor; when great accuracy is necessary the circular protractor with a glass centre is used, but the rectangular protractor or a scale of chords is sufficiently accurate for most telegraph surveys. Distances and offsets are plotted by placing a scale on the paper parallel with the station line, its divided edge marking distances on this line; and sliding along this, a short scale also divided, and with broad ends accurately at right angles to its divided edge, or a similarly divided set square; distances on the station line are measured off on the first, and offsets are drawn and measured off by the short scale or set square. Oblique offsets are protracted. On plans, trees, jungle hedges, swamps, nature of soil, material of river bottoms, anchorages, &c., are represented by conventional figures or written in words; buildings are either coloured or darkened by diagonal

lines, water is represented by light-blue with dark-blue edges; railways are represented by a thick black line or by two parallel lines; telegraph lines are represented by lines often coloured with conventional marks at intervals to represent posts, the number of wires may be written on the plan, or when few represented by parallel lines; masts at rivers, cable huts, &c., are represented by little figures somewhat resembling the objects, detached levels are written on the plan, and contour lines may be represented by dotted or continuous lines, or inclined ground may be shaded, the depth of shade varying with the tangent of the angle of inclination; hills may be represented by hatching at right angles to the contour lines. Plans of rivers have the depth marked; this is sometimes marked in dots, single dots signifying one fathom, pairs of dots two fathoms, &c. High and low water marks may be marked by lines, currents are marked in direction by arrows, and their velocity marked by figures placed against the arrows. Plans of tropical rivers, which during the rainy season are greatly swollen, should have highest flood level and maximum velocity of current shewn, and the highest and lowest levels of the water during the year; the highest known flood level should also be shewn. Lines representing water levels are really contour lines; irregularities of the bottom should be shewn by contour lines. On plans should be marked lines in which levels and soundings have been taken, bench marks, &c., so as to identify these on the section. On a section is drawn a horizontal line representing the datum level, on this is marked the positions of bench marks and other objects the levels of which have been taken; the distances between these objects should correspond exactly with the distances between them on the plan, and a scale should be marked on the horizontal line. In representing lines of soundings, the points where the soundings were taken should be marked, and the water level at the line may be shewn by a blue line; by shewing the positions of the points sounded, the reliability of the information given is shewn; in no case should a line representing the bottom of a river be drawn without thus shewing fully the data on which the section has been obtained. When an embankment or cutting is to be made near the river, as for erecting an office or a junction-house for the end of the cable, or erecting masts with deep foundations, the depth of the proposed trench or height of embankment should be represented.

402. In architectural and mechanical drawing perspective projection is seldom employed—it is then employed simply to shew how the object represented will appear when completed, and is used for structures in which elegance of appearance is important;

but perspective representations are not prepared for the use of workmen, as, although if correctly represented the actual dimensions of the object may be obtained from the drawing, such dimensions cannot be measured off directly—to obtain them considerable knowledge of perspective is necessary. Drawings (sometimes shaded) termed perspective representations, but not drawn by the strict application of the rules of perspective, are sometimes used to convey ideas of tools and similar objects, such drawings should be avoided as often useless and sometimes misleading. Drawings for the use of workmen and to convey ideas of mechanical and architectural objects, should be orthographical, or if required to convey general ideas isometrical projections; as by these means alone are the relations between the several dimensions of the objects actually represented by lines on the paper. These projections do not represent the actual appearances of the objects, but the dimensions of the objects may be obtained by direct measurements of the drawing. As a rule, bodies are projected on three planes—the projection on the horizontal plane is termed the plan, those on vertical planes are termed the front, back, and side or end elevations, and projections of sections are used when necessary but for most objects the above are sufficient. An instance of plan and section have been given in the case of portions of the earth's surface. Orthographic and isometrical projections may be considered representations of objects as they would appear if seen from an infinite distance in a direction at right angles to the plane of projection. Projections should be drawn either the natural size or to scale; the scale should be drawn on the paper or stated in words. A common way of expressing the scale in mechanical drawing is to state in words the relation the dimensions of the projection bear to those of the object—*e. g.*, "scale one-sixth," meaning the object is represented one-sixth of its natural size. As a rule, lineal projections are sufficient and should be preferred, shading should only be used when necessary to convey information. Shadows are assumed to be caused by light coming over the left shoulder of the draughtsman, at an angle of 45° to the plane of the paper, and to two planes at right angles to that of the paper and to each other and parallel to the sides and ends of the paper respectively; shading when necessary should be done in accordance with this conventional rule. The object of shading may often be attained by making some lines thicker than others, as in many of the figures in this book—*e. g.*, in fig. 54, A is a projecting object, B a hollow, *g*, *i*, *c*, and *d*, are projections, *j* is a depression; these facts being rendered evident by the difference in thickness of the lines, see also figures 55, 56,

and 73. The importance of the rule is evident, the draughtsman knows what he intends to convey will be generally understood without explanation. When complex objects have to be represented shading is useful. When objects are represented in section, the sections through the material are distinguished by the cut surfaces represented being hatched (see fig. 53); when several different pieces are represented in section they are frequently distinguished from each other by hatching lines drawn in different directions (fig. 65). Wood is usually distinguished in section by lines somewhat resembling the grain of the wood (fig. 44), coloured hatching may be used to distinguish different materials. Materials are usually distinguished by colours somewhat allied to the colour of the material represented; thus, copper is represented by brownish red, brass yellow, &c.; a special material may be distinguished by its name being written on the part of the drawing representing it. When only a portion of an object is represented and it is desired to convey this fact, the edges of the representation may be drawn to represent broken ends, as in figs. 54, 55, and 56. Construction lines, measurements, and axial lines are usually drawn in colour, to distinguish them from the representation of the object. Symmetrical objects need not be drawn completely, as an axial line and one side, or in circular objects a sector of the object is usually sufficient. Drawings for workmen's use should, when practicable, be drawn full size, otherwise they should be on as large a scale as practicable; the dimensions should be shewn in feet, inches, and eighths, these being the measures with which workmen are familiar; decimal divisions should be avoided as less likely to be understood. In designing, fractions should be avoided in fixing the dimensions. The elements of orthographic projection are very simple, and therefore easily learned; every workman should understand plans and elevations, but it sometimes occurs that even intelligent men do so only when assisted by explanation; in all cases, therefore, such projections should be strictly in accordance with rule, the several parts and materials should be carefully distinguished, and the drawings should furnish complete information, in order that if unintelligible to the workman he may procure the necessary explanation readily. When an object is made up of many distinct parts, or when it is very complex in form, isometrical projection is of great utility to convey an accurate idea of the object in its entirety. Orthographic projections of telegraph offices are usually drawn to exhibit their technical arrangements, for the use of the chief engineer and the officer entrusted with their care; these drawings should exhibit in coloured lines the positions of all wires

placed under or through the floor, walls, and ceiling, that wires placed out of sight may be readily found when required; they should shew the distribution and patterns of the several instruments, &c. The arrangements of small offices may generally be very readily represented by isometrical projection, and a better general idea of the arrangements conveyed thereby than by means of plan and elevation. In India drawings of all lines are kept, the plans are in books and shew the situation of the line with reference to the road, railway, track, or canal; description of construction, situations of angles, and details of villages, jungle, swamp, river crossings, store houses, testing posts, rest houses, cable huts, water supply, labour supply, camping ground, and all particulars of importance; sections of cabled rivers and elevations of overhead river crossings are also recorded. These drawings are of great use in estimating, executing and checking repairs, and inspecting lines; they are not costly, as they are not more accurate than necessary to utility.

PART III.

TELEGRAPH CONSTRUCTION, MAINTENANCE, AND ORGANISATION.

CHAPTER I.

CONSTRUCTION.

Section I.—*General Remarks on Designing.*

403. In designing a line the engineer must be guided by the particular circumstances of each case; if the line is only required for a temporary purpose, as during military operations, the structure should be of a less expensive description than when required to be permanent. Circumstances may render it necessary to restrict the first cost of the line, or on the other hand the highest attainable degree of permanence and efficiency may be required irrespective of cost. If a line is only the commencement of a telegraph system in a country, the route should be chosen with reference to the formation of a system; while if it be in extension of such a system, it should, if possible, be so chosen as to afford an alternative route to the traffic in case of accident to the lines already in existence. Unless for purely political purposes, whenever possible a line should be constructed through commercial centres rather than by the shortest line between the termini decided on, in order to increase the revenue from local traffic and afford facilities of communication to these towns. In designing lines along railways it is necessary to decide the minimum and maximum distances of the posts from the rails, if the line shall follow the curves of the road as nearly as possible, the headway to be allowed at crossings, and the sites of crossings. The distance of the line from the rails should be such as to admit of the telegraph material falling clear of the rails in case of accident, and yet near enough for inspection by a person travelling by train. The minimum distance is greatly contracted in populous countries to avoid encroaching on adjacent land; Blavier states there should not be less than 1·50 mètre (nearly

5 feet) between the wire and the plane of the nearest rail; this distance is very short, and only warrantable under the circumstances stated. The height of the posts should be considered, and the minimum distance increased to about once and a half the length of the post whenever practicable. Railway lines usually follow the curves of the road; they may be shortened by choosing the shortest route between the maximum and minimum distances when the road is not on bank, and such a route is consequently almost level. The headway necessary at crossings must depend on the height of the rolling stock, but a considerable excess is usually allowed. Regard must be paid to the existence of banks and cuttings, tunnels, bridges, &c. Lines on common roads may be as near the road as possible, avoiding encroachment; the maximum distance from the road should be such as to admit of inspection from the road. Road lines in India do not usually follow the curves of the road, but are constructed on the shortest line between the road and the maximum distance on each side of it, cutting the curves of the road; 30 yards from the road is a good maximum distance. In Europe the lines follow the curves of the road as a general rule. The angles and road crossings should be as few as consistent with observance of the above conditions, and the headway at crossings should be regulated according to the traffic; in Europe hay and vegetable waggons, and in India elephants loaded with tents, are the tallest objects passing on common roads, excepting in Eastern towns, in which large objects carried in processions pass along the streets during festivals. Where roads or railways exist, telegraphs should be constructed near them rather than across country, for facility of inspection; when these do not exist, long straight lines along the shortest route are not always the best—the best route is that offering fewest obstacles to inspection, carriage of materials, and electrical efficiency at all seasons, requiring the fewest expensive structures, as tall masts, &c., without being so much longer than the direct route as to counterbalance these advantages. As far as practicable streams should be crossed where narrow, and near fords or ferries; jungle is a permanent source of expense, and swamps render the line unapproachable during certain seasons—these should be avoided. Bridged rivers are crossed by the bridges, unbridged rivers by cables or air spans; the class of crossing chosen must depend on the result of a survey of the river, and the relative expense of cable or air span. As a rule air spans are far better than cables when practicable. Masts may be placed on land liable to inundation frequently with advantage, provided they are not placed in a current likely to prove a source of danger by bringing down drift-

wood or otherwise; wooden masts so situated are not attacked by insects, and the distance between the masts may often be shortened by choosing such sites. As masts can seldom be made angle posts, the line should approach the masts in a direct line with the crossing; the span should not be unnecessarily lengthened by crossing the stream obliquely. In some cases masts may be erected in the stream; these may be either simple masts or masonry, or screw piles braced together may be used to support a mast, according to the nature of the stream. For cables it is necessary to choose a line in which the bed of the river is as stable as possible, free from rocks, and not near an anchorage, the slower the current the better; as a rule the cable should be shore end, and should be laid loosely to provide for scouring and repairs. When expense is to be avoided, junction posts may be employed, but small huts of galvanised iron or other suitable material are as a rule better for containing the ends of the cable and land line and the lightning dischargers. Huts offer the advantages of being available for use as depôts of tools and small stores, for testing, or as temporary offices in case of accident to the cable; these huts need not ordinarily exceed in size 8 to 10 feet square; they should be placed on high ground, natural or made, and above possible flood level. The cable should be buried sufficiently deep between low water mark and the junction, to protect it as far as practicable against deterioration from atmospheric influences—3 or 4 feet is usually sufficient. For town lines it is necessary to consider whether the line should be overhead or underground; overhead lines are cheaper when few are required, when a great number of wires are required underground wires are usually preferred.

404. In Europe posts are almost exclusively of pinewood, iron posts being used exceptionally; they are usually injected, sulphate of copper and creosote being the substances most generally employed as preservatives. These posts are generally considered more economical than iron in Europe. Creosoted timber appears most durable; posts injected with sulphate of copper appear most durable in damp situations, those injected with chloride of zinc do not last long in calcareous soils, but are durable in sand. In America hardwood posts are common, the base of the post is charred and sometimes tarred; in Asia hard wood and iron are both used. Wood is more economical than iron when admissible, hence its general employment in Europe; but in tropical countries only mature wood of select varieties, without sapwood, can be used with success. It has been predicted that in time only metal posts will be employed, on account of their greater durability; it is contested that iron would certainly last ten times as

long, and not cost five times as much as wooden posts, therefore in the end the employment of iron must result in an immense saving; but the relative economy of employing iron or wood does not depend on the relative costs and durabilities alone, the engineer must decide the matter in each particular case. Compared with wooden posts, iron posts possess the advantages of greater permanence of form, they require therefore less attention, and from their uniformity the fittings are readily accurately applied or altered by unskilful workmen; they are generally lighter and more portable—great advantages where carriage is very expensive or difficult to procure; and their employment removes all uncertainty due to the employment of timber, where only selected timber will resist the destructive agencies present; these advantages together with that of greater durability have led engineers to employ iron posts in Asia. In Europe iron poles are used exceptionally; hollow iron poles are commonly used to contain the connections of overhead with subterranean and subaqueous lines. Cast-iron poles are often employed for town lines, they are usually ornamental, and may be bronzed or painted and gilt; they are usually supported on masonry. Iron poles are usually of cast iron at the lower part to a foot or more above ground, and of wrought iron above. For temporary lines during repairs, &c., bamboos or other endogenous wood may be used with advantage; an excellent mode of supporting a line is to tie bamboos together to form shears, burying the legs 9 inches or 1 foot, and placing the line above the shears opening across the line. Posts are usually buried to a depth varying with the nature of the soil, the tension on wire, the height of the post, and whether cross feet or earth plates be used or not, and at angles whether ties be used or not. The hold of a post on the ground may be increased by distributing the pressure by means of timber or large stones, by filling in the hole with stones or bricks, or by inserting the post in masonry. Ordinary posts do not require such expedients, but tall posts which cannot be stayed and are yet required to resist a transverse load, must be very firmly fixed. Two large stones or blocks of wood are commonly used for the post to bear against—one is placed near the top and the other at the bottom of the pole hole; old bricks or stones are sometimes used to fill the hole; masonry and brickwork plinths are used but seldom, and then to support ornamental pillars in towns, for masts placed on streams, or for poles erected on rock. In India lines are erected over rock either by fitting the pole in a shallow hole jumped for the purpose, or by erecting cairns round the poles. The following are examples of posts actually used:—The small fir poles used in France are 19·5

feet long, 4·7 inches diameter at base, are buried 4·92 feet, they resist safely a horizontal force of 48 lbs. applied at the top, 61·72 lbs. 3·25 feet from the top, and 77·15 lbs. 6·5 feet from the top. The largest poles are 39 feet long, 10 inches diameter at the base, they are buried 6·5 feet, resist safely a horizontal load of 218 lbs. applied at the top, of 242·5 lbs. applied 3·25 feet from the top, and 271 lbs. at 6·5 feet from the top; the posts are conical in shape, the diameter at the top being at least two-thirds that at the base. From the above data may be calculated the strength of similar poles, the strength being inversely as the length and directly as the cube of the diameter. Masts up to 33 feet long are commonly buried 6 feet 6 inches, and those 40 feet long 8 feet. Masts to be well stayed need not be buried more than 8 feet, but it is usual and preferable to bury masts from 75 to 110 feet long 10 feet deep, and this is adhered to even when cross feet or earth plates are used. It is manifest the hold on the earth should not exceed the transverse strength of the mast or pole, and this condition has been overlooked sometimes in designing earth plates and cross feet. The iron posts used in India 6 to 8 inches diameter at the base, standing 16 feet clear, and furnished with two cross feet 3 feet long, are buried about 3 feet, and this is sufficient; it is sufficient in good soil without cross feet if the hole be bored, the breaking strain of the post being 6 cwt. Siemens' poles to stand 17 feet clear are buried 2 feet 8 inches; these are only 4 inches diameter at base, and are fitted with earth plates 1 foot 9 inches square. When concave earth plates, as buckled wrought iron or castings, are used, the transverse strength is greater with the concavity upwards, but in soft soil the earth plate is more efficient to prevent sinking when the concavity is downwards. Earth plates are usually bolted to the post, cross feet are passed through holes in the foot of the post, cast earth plates are screwed or locked to the post. The heights of posts are regulated according to the number of pairs of cross arms or brackets, and the height required above ground; ordinarily 14 feet or 15 feet is sufficient distance between the lowest wire and the soil. Railways and military lines are sometimes lower, particularly the former; when within the railway fence the distance may be reduced to 10 feet. At road and railway crossings and in towns higher posts are necessary; on houses short posts are used, usually fitted into sockets, and held by stays. In Prussia iron poles are only used on bridges and for inserting in masonry and brickwork. The commonest length for wooden poles is 27 feet, 5 to 5·5 inches diameter at top for intermediate, and 7 to 9 inches for angle and terminal poles; when considerable strength is required, the poles are coupled to form

a triangular frame. The Indian wooden lines are of hard wood; a common diameter for posts of sâl and teak is 6 inches, with a length of 14 to 16 feet from the ground; terminal posts are from 9 to 12 inches in diameter. The wood offers nearly twice the resistance to a transverse load offered by fir. The best hard wood, as teak and sâl, should be mature squared timber; 5 inches square is large enough for ordinary posts 16 feet long, and 6 to 9 inches square is large enough for terminals and other poles of the same length required to resist severe transverse loads. If the load be fixed in direction, the post should be rectangular, and its longest transverse dimension should be placed in the direction of the load, and generally the strength of a post may be increased economically by increasing one dimension only. If posts differ in strength in two transverse directions, then on straight sections of line they should be placed with their line of greatest strength at *right angles to the alignment*, as the wires serve to support the post in the other direction; if timber has to be cut up, it may be economically cut rectangular rather than square. The transverse specified strength of the iron posts used in India is—for the Hamilton 16 feet post, about 500 lbs., but they are as a rule stronger; and for the Siemens' 17·5 feet post, 560 lbs.; 500 lbs. is the minimum strength admitted for iron posts in India whatever their height, but there are weaker masts standing. The number of poles per mile depends on the number of wires, on the extra strength required to resist frost, &c.; on the sharpness of the curves, particularly when ties or struts are not used at all the angles; on the inclination, if any, of the ground, and the existence of hills conveniently situated for large spans. On level ground sixteen posts per mile are sufficient for two wires, the wires being strong and not liable to accumulations of frost; for a greater number of wires, and when great strength is necessary to resist frost, the number of posts may be increased up to thirty. Some engineers recommend up to as many as forty, but the necessity for so many must be regarded as very exceptional indeed. In Prussia twenty-two to twenty-five posts per mile are used on straight lines, and more on curves bringing the average to twenty-six to thirty poles per mile. In India the number of poles per mile is ruled by an empirical formula; it is four times the quotient of the weight of wire per mile by the ultimate transverse strength of one pole—100 yards is the maximum distance permitted between the poles. The variations necessary on inclines and curves may be calculated for each mile, and the extra poles necessary for road crossings, and to raise the line above obstacles, may be obtained by observation; a post close to the road is necessary on each side of a

crossing. Trussed or coupled poles are used to enable longer cross arms to be used, and thus provide for a greater number of wires, or to obtain greater strength at angles, stretching posts, and terminals. Increased height is sometimes gained by coupling two or three poles together, and supporting another pole by the combination; as a rule, a single large pole is cheaper than a combination, and should be used when obtainable. Stronger poles are often used for angles and draw poles than for intermediate poles; when angle poles are fitted with ties they need not generally be stronger than intermediate poles, the tie and intermediate pole together offering a resistance to transverse strain enormous as compared with the additional resistance it is possible to confer by using a stiffer pole; even in metal poles, in which the strength can be regulated economically, the draw poles and angle poles are not made more than twice as strong as intermediate poles. As a general rule, additional transverse strength is more economically conferred by a tie than by using a stronger pole, or coupled or trussed poles; sometimes stronger poles are used together with wire ties for angles, and they are very generally combined for terminals. When the wire is stopped at each insulator draw poles are not necessary, and they are not used so frequently as formerly; but many engineers prefer to use them, and consider their disuse a mistake. They are really useful for town lines, particularly when the number of wires is large; but they are objected to as expensive, because they are rendered unnecessary by the practice of stopping the wire at each insulator, and with some kinds the insulation is inferior. Three or four draw posts per mile is about the average, in towns the number used is greater according to the conditions to be fulfilled. At a stretching or draw post the wire is fixed but not actually terminated, and, excepting in case of accident, the tension on one side is balanced by equal and opposite tension on the other. It is necessary to employ terminal poles at offices, cable junctions, and at long spans, such as river crossings. A terminal pole may be an ordinary pole strongly tied by ties placed opposite to the loads, or a stronger pole with or without a tie or ties, or a coupled or trussed post; this should be decided after calculation. In many cases the stronger or compound poles may be dispensed with at a considerable saving in favour of an ordinary pole tied. Poles of pinewood any given length do not differ much in strength; hence tying, trussing, or coupling are employed necessarily. Metal poles offer the additional alternative of increasing their strength by increasing the section of metal, or altering their proportions. Poles intended to bear vertical pressure only should of course be placed vertical; when subjected to trans-

verse stress a rake towards the direction from which the straining force acts is advantageous, the only objection to it is the unsightly appearance of the line—the advantage, in any case, may be readily ascertained by application of the triangle of forces. The cases in which rake is given are when violent gales may be expected from a certain direction, when poles are erected on a curve and not held by ties, and angle posts are sometimes inclined towards their anchors when held by ties; in the first and third cases rake is not necessary. Well-constructed lines in India resist the most violent storms with vertical poles. The only case in which angle poles should be inclined is when straining screws are not used in the ties; the rake should be very slight indeed. In the second case mentioned above, posts may be raked; but it should be remembered the gain is very slight, the ratio between the transverse resistances of the erect and the inclined posts being inversely as unity to the sine of the angle of inclination.

405. Stays are used to keep poles vertical in order to prevent transverse stress, they are used for masts at river crossings and for very tall posts generally; stays termed "cross stays" are also used sometimes at regular intervals along lines erected in places where violent storms occur. These stays are erected in pairs at right angles to the direction of the wire, a pair being erected about every quarter of a mile; they are seldom used, but may be employed with advantage sometimes when many wires are erected on tall posts; cross stays are not usually fitted with straining screws, nor attached to the posts by clamps. Stays and ties are usually connected to the poles by means of clamps or clips, and at their lower end to anchors buried in the ground; they are frequently fitted with straining screws for tightening them, the straining screw being inserted in the stay or tie about 5 feet from the ground. The stay or tie proper may be of iron rod, single wire, or wire-rope; as wire-rope rusts rapidly when buried the buried portion should be of rod or the thickest wire. Rod stays are usually heavier in proportion to strength than wire stays. They are sometimes made with hooks to connect them with the anchor, straining screw, and collar; but unless the rod is much thicker than required for tensile strength these hooks open when strained, hence forged rings or eyes should be preferred. Single wire ties are unreliable, and should not as a rule be employed, if however such be used the eyes should not be made by twisting the wire round itself, but by bending it round and binding it with binding wire, as in making a Britannia joint; the thin wire should be put on with a mallet, and instead of finishing off as in a Britannia joint, its ends should be twisted together and bent down. Iron-wire

stays are often made of pieces of line wire, and stays are economically made by twisting two or three thick wires together by hand; in doing this the wires should be twisted sufficiently to prevent slipping one on the other when strained; they should be stretched and twisted from one or both ends, as in ropemaking by hand, a tap with a hammer being applied to close any strand seen to rise. A wire-rope made of thin wires should be spliced to form an eye, and such eyes should be made over moulds or dead-eyes of wrought iron, to prevent them collapsing when strained. Stays for masts are usually spliced in this manner, but sometimes inferior work is used for ordinary poles. Eyes should not be formed in wire-rope by twisting the strands round the rope, the end may be secured by a long and tight serving of wire, or by this combined with a simple eye-splice, the strands being passed only once through. In making an eye-splice on wire-rope short servings of wire should be applied before and after the strands have been passed through the rope, the first keeps the strands together at the eye while the splice is being made, the second fastens down the ends; a serving mallet and a marlinespike are necessary to make a good splice. Splices when finished should be painted, oiled, or tarred, as the galvanising or varnishing on the wire is damaged by splicing; they should not be made short so as to kink the wire, and the marlinespike may with advantage be wedge-shaped rather than pointed; when dead-eyes are omitted eyes should be somewhat flat, or they may cause inconvenience by flattening when strained, and thus allowing the stay to stretch. Ties are fastened to posts by saddles or clamps, or sometimes in the case of wire stays by an eye being turned at the end of the stay round the post; collars are sometimes simply a continuous ring of iron, the post is made conical, and the collar is passed over it and slipped down as far as it will go; continuous collars are suited to iron posts, these being uniform in size and not liable to alteration by weathering of the external layers; but wooden posts differ in size, and a shoulder should be cut to support the ring and prevent it from slipping down as the post shrinks or decays; nails and staples are sometimes used for this purpose, but are not to be recommended. Open collars or clips fitted with ears for a bolt, or collars formed of two saddle pieces clamped round the post by two short bolts passed through ears, have the advantage of being adjustable, and are in general use in India. A ring-bolt passed through the post and nutted or clenched on the opposite side is used because cheaper than a collar, but it is inferior in strength and durability, it is objectionble as hastening decay of the wood, and as rendering it unsafe earlier when decay has occurred.

Collars on wooden masts should have bolts for tightening them, and in addition a shoulder of wood should be cut for them to rest on when practicable. Great care should be bestowed on fitting the collars to high masts, as the mast may be rendered unsafe by the slipping of a collar, and the collar may, by holding the fibres together, materially increase the durability of a mast when badly weathered. Stays and ties may be fastened to masonry and brickwork by means of ring-bolts passed through or into the masonry at right angles to the tension; pieces of durable wood, brackets of cast iron, or projecting stones, may be let into the masonry to form points of attachment; when necessary the force should be distributed by means of iron plates or timber, the unsuitability of masonry and brickwork to resist tension should not be lost sight of. When brickwork chimney stacks and similar structures are made use of to support lines, or as attachments for stays or ties, their tenacity may be increased by encircling them with bands of iron, and their stability by staying them or by tying them in a direction opposite to that of the transverse load they are required to resist. Ties are sometimes anchored to logs of wood buried, or to stout pickets of timber; the inferior durability of timber under such circumstances should be considered; when wooden posts are used wooden anchors are admissible, as the anchor will last as long as the post, but if iron posts be used stone or iron anchors should be employed. When procurable on or near the work large stones form excellent anchors, they are attached by several turns of thick wire and buried. Broken castings may be used as anchors, such as pot sleepers, the cast iron segments of posts broken in transport, &c., these are applied in the same manner as stones. Anchors proper are either of cast or wrought iron, cast-iron anchors are usually saucer-shaped, with a hole in the centre across which a stout wrought-iron pin is inserted in the casting to form a point of attachment in the tie, the end of the tie is attached by bending an eye round the pin. Buckled plates of wrought iron are used as anchors, they are attached to an earth rod passed through a central hole and nutted on the opposite side; this rod has an eye or hook at the other end to which the wire tie is attached. Wrought-iron anchors are much lighter than those of cast iron, but they are less durable and more expensive. Anchors should be buried in a plane at right angles to the load, and with their concave side towards the tie; they need not exceed 18 inches in diameter, nor be buried in ordinary soil lower than 3 to 4 feet. Care should be taken in putting in anchors that the stay be not bent against the edge of the anchor hole, because in this case when the earth is softened by rain the

stay will become slack, a notch should be cut in the edge of the hole to admit of the stay being perfectly straight from the anchor to the collar. Stays should be placed as nearly as possible opposite to the force to be resisted, thus at terminal poles the brackets are usually placed in the alignment, if however, a long cross arm be used placed at right angles to the alignment, the tie may be branched and attached one branch to each end of the cross arm; in the case of a number of brackets on a post, a stay may be branched and one branch fixed above the other below the brackets. When it is desirable to place stays above insulators, they can seldom be anchored sufficiently distant from the post to clear the insulator. In India this case is met by attaching the tie to a short arm fixed at right angles to the pole, but this diminishes the efficiency of the tie by rendering it more nearly vertical; a double tie the branches of which are kept apart by a short strut brace so as to clear the bracket, one branch of the tie passing on each side of the bracket or insulator, may be used. When a post is so near a building, that a single tie cannot be anchored in the proper direction, two ties may be used instead of one. Sometimes ties are forked in a vertical plane, being attached to the pole at two points in its length, and joined to form a single tie above the ground line; these branch ties should have the branches as long as practicable, the lower part attached to the anchor should have a ring or eye at its upper end through which the piece forming the branches is passed and is free to move. Double ties should be so placed that the resultant loads on them act as that on a single tie. The tension on a tie and the pressure on a tied pole, may be expressed in terms of the tension on the line by means of the triangle of forces. On consideration it will be evident that ties anchored close to posts are less efficient than when anchored more distant, hence ties and stays should not as a rule be anchored nearer the post than one-third the height of the attachment of the stay above the ground. In ordinary poles half the height of the pole or somewhat more should be allowed between the pole and the anchor, and mast stays may, when ground is available, be spread still more. At terminal poles the ties should be anchored a pole's length from the foot of the pole. Small oval linked chain and jointed rod are used for mast stays, these are applicable to lower masts. For tightening stays straining screws are necessary, and without them or an equivalent contrivance, stays cannot be properly tightened; hence all stays should have straining screws, excepting cross stays. Angle-pole ties may, however, be tightened without straining screws, by erecting the pole very slightly inclined towards the anchor, fitting the tie, burying the anchor, and then pulling the pole upright in

order to tighten the tie. Terminal poles fitted with two ties on opposite sides need only one screw; one tie may be put in without a screw as for an angle pole, and the two ties tightened by the screw on the other. Mast stays might be tightened in the same way by using one screw for each pair of stays, but in this case a screw should be used for each stay; because the stays being long require a great length of screw to tighten them, large masts cannot be moved conveniently to tighten the stays, and an accurate adjustment is essential. Heavy stays to lower masts may be hauled tight and fixed, the screw being dispensed with, but the screw should be preferred. Screws are commonly inserted in angle ties for convenience in making adjustments from time to time, and to place the post more accurately vertical than is otherwise possible, but they are expensive. Stays and ties to ordinary posts may be tightened by raising the clamp and wedging it up; this is applicable to continuous collars and iron posts, it is cheaper than using screws, but less convenient, it is applied to the Siemens' pole. When ties are used without screws or other contrivance for adjusting them, the post should remain slightly inclined towards the anchor when the wire is mounted and tightened to allow for possible slight dragging of the anchor, flattening of the eyes of the tie, &c.; slightly conical iron poles made up of several sections, joined by being fitted one within the other, should be stayed or tied with care when the joints are numerous or the poles are high; such poles when above 30 feet long shorten after erection, hence they should be first stayed temporarily for a short time, and the permanent stays adjusted after the post joints have been closed by the weight and tightening of the temporary stays. Straining screws are made of several patterns, some have a double male and two female screws which act together, others have only a single male and female screw; a solid and compact form should be preferred, as some kinds are liable to fail where welded at shoulders; they are usually turned by using a rod of iron as a lever. The opening for insertion of the lever should be large enough to admit a crowbar or other stiff rod available, the female screw should be long enough to prevent the worm being torn off. The straining screw unless well made is a source of weakness. In one form of straining screw a simple ratchet tooth and notch are so arranged that the screw cannot be loosened while the stay is tight, it cannot therefore be loosened by mischievous persons. Screws are more necessary in towns than outside of them, as they render it easier to effect adjustments rapidly and accurately in a confined space. Tying is preferred to strutting, but when the latter becomes necessary for iron poles, L or T iron struts may be used, and for wooden poles, wooden

struts; but increased strength is usually gained in the wooden posts by coupling two posts into the form of the letter A, this expedient is in general use in England, France, and Germany.

406. Pole holes may be bored or dug; when cross feet or earth plates are necessary the holes are necessarily dug. Bored holes, or holes jumped with a crowbar or *khuntie*, have the advantages of being accurately placed, being small unskilled labour may be employed for erecting the poles; the pole is erected cheaply and quickly, because little ramming is necessary, it is strong because the earth is left undisturbed near the pole, and in many cases cross feet and earth plates may be dispensed with. When holes are dug they may be square or circular, or long and narrow, it being necessary to allow sufficient room for the workman to use his tools in the hole, and for the cross feet or earth plate if any; to remove as little earth, and depart as little from the site marked for the pole as practicable. The long holes are usually placed with their longest diameter in the alignment, but sometimes across it—the former appears preferable to the latter. Holes for poles without cross feet may be most economically dug long in the alignment, being made narrow at one end, so as just to receive the post, the bottom should be made in steps, the narrow end being the deepest, the depth at the narrow end should be completed by jumping; this hole is conveniently shaped for raising the post, comparatively little earth is removed, the alignment cannot be departed from, the post is very firm immediately after erection, and comparatively little ramming is necessary. The above mode of digging is described by M. Blavier; Shaffner states holes are dug in America 2 feet with a shovel, 15 inches wide, and then 3 feet with an auger. Holes may be jumped with a khuntie or jumper, or bored with an auger.

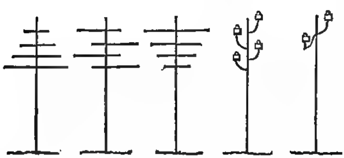
407. After erection the poles may be numbered, this numbering is very useful and costs but a trifle. Sections of line are best distinguished by the stations between which they run; the poles on each section may be numbered in series distinguished by letters of the alphabet, numbers being used to distinguish the poles in each series; a good method is to measure the line, and mark on the nearest post to each complete mile its distance from the station started from, in miles and furlongs measured on the line, and also the number of poles in the same distance; by this system the length of line and the number of poles are given at the end of each mile, and any pole may be described by its number, and the number of the mile in which it stands. It is not necessary to number every pole, one pole per mile is generally sufficient; the numbers or letters should be large, they are usually put in the form of a fraction, and should be painted in

conspicuous durable paint on the side of the post exposed to view from the road, rail, canal, footpath, or other track near the line; when no such track exists the numbers should all face one way with reference to the direction of the line. Lines have usually a distinctive number in a printed list, in which the route of, and stations on, each line are stated, and by this number the lines are distinguished in estimates and other records. Lines may be distinguished by circuit numbers, these are given from the chief office and are applied to particular wires according to convenience. Lines are also known by numbers distinguishing them by their relative positions on the poles, and underground wires usually have each a distinguishing number. Wooden poles should be stamped with date of erection.

408. Insulators are either fastened to poles directly by their stalks or by ears or saddles formed of the procelain or by expansion of the metal cover, or they are supported by brackets or cross arms. Insulators fixed to poles directly by their stalks have the stalks either pointed or formed into a male screw, to be inserted into the wood of the post, or they may be flattened and fastened to the wood by a binding of wire, or by screws passed through holes made for their reception; to keep the cup clear of the post the stalk is bent twice at right angles, or into an S curve. When insulators are attached by procelain ears screws are passed through the ears into the wood; when they are attached by the metal bell the metal of the bell is expanded into ears, through which screws are passed, or into a saddle, which may partially embrace the post and be bolted on each side by bolts, passed also through a second insulator, or through a metal saddle; or a long bolt bent round the post may be passed through the ears of the insulator, and secured by two nuts, one at each ear. Light insulators for military lines are usually attached directly to the posts by their caps or stalks; when attached to living trees, screws should be used in preference to binding with wire, as the latter kills the tree. Insulators are attached to wooden posts by spikes, but screws should be preferred. In France the insulator stalks are spiked to the poles, in Prussia the insulator stalk is screwed into the pole. Insulators are commonly supported by brackets or cross arms, the brackets used are mostly of malleable cast iron galvanised, seldom of wrought iron, ordinary cast iron is not usually suitable, a hollow form is adopted to combine strength with lightness; the best mode of attachment to the post is by means of ears, the brackets being used in pairs, and clamped round the post by two bolts; this mode of supporting insulators is employed in India. With wooden posts projections on the bracket are inserted in the wood of the post, to prevent the

brackets sinking when the wood shrinks or gets weathered; the brackets may be fixed by wood screws to wooden posts, or they may be made in pairs with a ring between them to be passed over the post, but bolts are better. When only one bracket is required on the same level on each pole, then a bent bolt or a saddle may be used, as described above for fixing insulators when used without brackets. On wooden poles the insulators, when numerous, are supported by cross arms of oak, the stalks of the insulators are placed in holes in the cross arms, and the latter are bolted to the pole by bolts passed through the cross arm and pole. This mode of support is in general use in England. The oaken arms should be well oiled and painted. Sometimes insulators are placed on the tops of the poles; lightning spike sockets when such are placed on the tops of the poles, should be the same size as the bracket sockets for the insulator stalks, as a line may then be erected if necessary on the top of the poles by fitting insulators instead of lightning spikes in the cap sockets. Insulators on the tops of poles are liable to injury from lightning, a lightning rod should project above the insulator. Lines should not, as a rule, be erected on the tops of the poles, but by so placing a wire a considerable saving may sometimes be effected in erecting an odd number of wires. Brackets and cross arms are a more expensive mode of supporting insulators than by either lengthening the insulator stalk or expanding the procelain cup or metal guard of the insulator, to form insulator and bracket in one piece; but the former are more convenient, as carrying more wires and admitting of removal of the insulators when injured or for cleaning. For light temporary lines, the insulator and bracket may be in one piece with advantage. To fix many lines against a wall sometimes a short pole is fixed to two or more brackets let into the brickwork; this is common in tunnels and overground town lines. Sometimes on bridges poles are supported on brackets let into the brickwork, these brackets are merely pieces of timber or iron brackets built into the bridge and supported by oblique struts, usually resting on the projection of a string course below; but the wires are more commonly supported on long brackets projecting from the outside of the bridge, built into the masonry or brickwork, or bolted to the wood or ironwork, according to the material of the bridge. Oblique struts should be used on masonry bridges, excepting when the weight of masonry above the point of insertion of the bracket is considerable, or the number of lines very few; and on iron girder bridges either clips should be used, or care should be taken to put bolts only in the compressed flanges of the girders. When many wires are erected on the same line of poles, brackets or cross arms render it possible to use lower

poles than could be used without them. Cross arms may be strengthened when long by oblique struts bolted to them and to the pole. Cast-iron poles usually have large cast-iron ornamental brackets, either cast with the pole or bolted on; cast-iron brackets are sometimes used for fixing in masonry and brickwork, they should be annealed. The minimum distance allowed between the wires is 1 foot, but it is better to allow at least 18 inches, as multiple lines are liable to contact if the wires be nearer. In order to separate the wires and diminish the injurious effects of the breakage of a wire as much as possible, the brackets are arranged in various ways on the poles; and when several lines are borne by insulators screwed or spiked to the poles, the insulators are not fixed in pairs on the same level, but those on one side of the pole alternate with those on the other. Figs. 75, 76, 77, 78, 79 represent common modes of arranging cross arms and brackets; in fig. 75 the greatest number of wires being on the lowest bracket, and the number diminishing on each bracket to the top one, if a wire break it is more likely to be a low one, because the average height is less than if the brackets were of equal length, and the resultant of the load is placed lower on the pole.



Figs. 75. 76. 77. 78. 79.

Fig. 76 has the advantage of placing a greater average vertical distance between the wires, and also reducing the liability to contact in the case of breakage of a wire. Insulators should be so arranged on brackets that the wires may not be directly over each other, brackets carrying single insulators may be of different lengths; and cross arms carrying several insulators should have the insulators so arranged that the wires on one cross arm should not be in the same vertical planes as those on the cross arms immediately above and below respectively on the same post. Malleable cast-iron brackets are often made uniform in size regardless of the number to be used, so that several wires are placed in the same vertical plane, and if an upper one break it falls over those beneath; it is better to have such brackets of unequal lengths, a pair of brackets to consist of a long one and a short one, and the long and short brackets so arranged as to alternate with each other on each side of the post. Wires may also be separated by using curved brackets in pairs, each pair being arranged as in fig. 79; the wires are farther apart, and as wires on the same level are liable to touch and even twist together

in the centre of the span, it is of great advantage to place them in different horizontal planes when the distance between them is short or the span long. Fig. 78 represents the arrangement of insulators adopted generally in France. In India when the span exceeds 120 yards no two wires on the same post are placed in the same horizontal plane, but the arrangement shewn in fig. 78 is adopted; for shorter spans the wires are usually placed in pairs on the same level, and the brackets are uniform in length; but when the lines are very numerous and cast-iron poles are employed, long arms are used, arranged as in fig. 75. When many wires are erected on the same poles, great care is necessary in arranging them to avoid liability to contacts without inordinately increasing the length of or distances between the brackets.

409. The essential parts of an ordinary insulator are—a bell, or several concentric bells of porcelain or brown stoneware, usually highly glazed, and a stalk of wrought iron or steel cemented in to support both insulator and wire or only the wire. Several bells are employed to increase electrical efficiency, they are as a rule formed in one piece. The porcelain cup is sometimes protected by a hood of ordinary or malleable cast iron. The insulator is supported and fixed to the post either by the hood, which is at one part expanded into a saddle with ears or otherwise adapted by its shape to the purpose, or it is supported by its stalk, which is fitted into a hole in the bracket arm or pole roof. The wire is supported and secured in the case of a hooded insulator by lugs, grooves on the hood, or by a hook on the lower end of the stalk, and in uncovered insulators by grooves or notches on the bell. The wire is secured to the insulator by wire serving, cams, wedges, or by winding the wire round the bell in a groove for the purpose. The slightest crack in the insulating material is sufficient to greatly impair its efficiency (electrically), a patch of the glaze should be ground off before testing an insulator. The object of a fine glaze is to hinder the adhesion of dust and assist in its removal by rain. Double bell insulators are more difficult to clean, and more liable to become inhabited by insects than single bells, but their insulating property is higher, and they are hence preferred for long lines. For short local lines in towns single bells may be used, they are sufficiently good as insulators, easier to clean, less liable to get dirty, cheaper and commonly stronger than double-cup insulators. The inner cups of insulators are made shallower than the outer cups, and when more than two cups are used the innermost is the shallowest; more than two are seldom employed. The stalks of insulators should be of wrought iron or steel, they are usually galvanised, slightly tapered towards the lower end to

fit the socket of the bracket; terminal and angle insulator stalks are sometimes secured in the bracket by a nut screwed on the stalk under the bracket, and intermediate insulators are commonly secured by a piece of wire laid in a groove on the stalk below the bracket, and its ends twisted together; but if a line be properly marked out, the weight of the wire is sufficient to keep the insulators down, and the necessity for fastenings may be regarded as exceptional. The thickness of the stalk should be such as to enable it to resist the transverse load at the acutest angle permitted on the line, and care should be taken that the cement used is not one likely to destroy the porcelain by expanding. The iron-hooded insulators used in India will carry a $5\frac{1}{2}$ B.W.G. wire at an angle of 30°. Sometimes the stalks of insulators are covered for a short distance with ebonite to improve the insulating property; but the utility of this is doubtful, as the coating soon strips off, probably by reason of the sulphur attacking the iron. When the wire is suspended from the insulator by the stalk, a hook is turned on the stalk to receive the wire; to prevent the latter being lifted out the hook is sometimes formed by bending the end of the stalk, into a helix. When it is required to fix the wire to the stalk it is suitably shaped, and fitted with eccentric cams, openings for wedges, or pressure screws. The end of the stalk fitted in the bell is roughed or grooved, and the inside of the bell is grooved to assist the action of the cement. If the quality of the materials and nature of the joint be considered, it will be obvious suspension of the wire from the stalk is inferior in strength to the combination in which the wire is supported on the bell, and the bell on the stalk; and in the latter case, injury to the porcelain which loosens the stalk, is not so likely to entail fall of the wire. Insulators supported on their stalks may be broken into many pieces, and the tops may be entirely removed by lightning, and even under these circumstances the wire very seldom falls if the binding be well put on, or if the iron hood be not entirely removed. Insulators may or may not be covered or partially covered with an outer cup or hood of metal; some insulators are made very thick, and have no metal covering, others have a metal cap only, while others have either a continuous or a perforated metal bell cover, forming an outer bell covering the porcelain. The metal covering is cemented to the porcelain in the same manner as the stalk, but frequently with an inferior cement; it is frequently of cast iron, but malleable cast iron is far better, and more economical in use. The principal uses of the metal covering are—*Firstly*, To strengthen and protect the porcelain from blows; *secondly*, to hold the porcelain together in

the event of it being actually cracked or broken; *thirdly*, to form and carry lugs, cams, screws, grooves, saddles, &c., necessary to hold and secure the wire and to fix the insulator to the post; the properties of porcelain being such that these cannot be formed of that material, but must be formed of metal and applied; hence, if the insulator be required of any but a very simple form, a metal cap or cover is a necessity, while its employment not only diminishes the risk of breakage, but it prevents, as a general rule, the immediate consequences of such breakage. *Fourthly*, The metal cover hinders radiation, and diminishes therefore the deposit of dew on the porcelain. When the line wire is bound to every insulator by wire passed round a neck or groove of the insulator, the porcelain, if cracked, is held together by the binding without the presence of a hood. The usual form assumed by the metal cap is either a bell similar in shape to the bells of porcelain, or it is merely a cap covering the top of the porcelain, the porcelain below this cap being freely exposed. The object of having the hood pierced with large holes, as in some patterns, is to admit rain in order that the porcelain may be washed thereby, and so combine this excellence of the uncovered with the greater strength of the covered insulator. In Europe iron-hooded insulators are seldom used; but in Asia, and generally when the lines are situated in regions subject to severe storms, and where frequent inspection is impracticable, iron-hooded insulators are preferred. A swinging insulator for attachment to living trees has been invented by Colonel Chauvin, but it does not appear to be in general use—it does not differ in principle or general form from the insulators described above, excepting in being suspended. Insulators, although the same in principle, are made of many patterns and several sizes, according to the ideas of the inventors and the purposes for which required; of the different patterns some are made with long narrow bells particularly Clark's pattern, some patterns are rather conical than bell-shaped, others are nearly cylindrical, some have the head perfectly cylindrical. In some patterns, particularly those without hoods, the wire is laid in a side groove or neck, or in a top groove, while those with hoods generally carry the wire on lugs, on the top, or by the stalk. In Varley's pattern the edge of the cup is of a form calculated to throw off water (fig. 66); in some patterns the cups are separated by an inch, in others they are less than half an inch apart. The porcelain is in some patterns much thicker than in others, being usually thicker when no hood or only a cap of metal is used. White ware is used most, but brown ware is also used; the brilliancy of the glaze

and vitreous appearance of the fracture differ in different patterns. Insulators differ considerably in size, some patterns being much larger than others, but the very large heavy patterns formerly used are not now employed. Most patterns are made in different sizes; the smallest sizes are only used for military lines, and when the wire is very small, as 12 to 16 or 20; the next sizes are used for intermediate insulators on ordinary lines according to the size of the wire; and the largest and strongest are used for terminal poles, draw poles, control or testing poles to support shackles and winding drums, and sometimes for angles. Insulators should be tested by a steady load, and by a suddenly applied load, as their efficiency depends in a great measure on their power to resist shocks. It was formerly a general practice, and it continues so with some engineers, to fix the wire to the insulator at intervals of four to ten poles, leaving it free to slip through the other insulators; at present a common practice is to fix the wire to every insulator by means of binding wire put on, often with a mallet of peculiar shape, in a manner differing with the pattern of insulator used; this practice has many advantages, it checks the wire in case of breakage, it prevents inequality of tension due to alterations of temperature between unequal spans, it prevents some classes of accidents, is cheaper than employing stretching insulators, and performs their office more generally. In some stretching insulators, however, the wire is held at two points, a ring of spare wire between these points is thus always available for repairs—this is the case in Siemens' pattern; breaking of the wire is an accident which occurs very seldom indeed, and it does not appear necessary therefore to provide for it in this manner. Small drums and ratchets are sometimes used, supported by a strong insulator, for tightening the wire when necessary, and for allowing slack after accidents; these winders are used less often than formerly. Sometimes posts at intervals are fitted with a double bracket carrying two insulators, both in the alignment of the same wire, these are termed testing or control posts, brackets, and insulators; the wire from each side is fixed to a separate insulator, and the solution of its continuity between the insulators is bridged by thin wire, or by the two ends of the line wire; a screw clamp is used to connect the thin wires, and frequently the ends of these wires are furnished with discs faced with platinum; this arrangement is to admit of the line being disconnected for testing it, or signalling along it in sections or from particular points. The purposes of a control post are fulfilled by a cheaper and more simple arrangement—viz., a prolate spheroid, or in common language an "egg-shaped" body of porcelain or stone-

ware, having two grooves round its greatest circumference at right angles to each other, is inserted in the line, by cutting the wire making two eyes linked together, and inserting the testing ball between them, so that the wire lies in the grooves; this causes a solution of electrical continuity in the conductor, and the interval is bridged by thin wires fitted with platinum discs, held together by a screw; this arrangement is cheaper and lighter than employing two insulators. A testing ball or some equivalent arrangement is usually placed at intervals when the offices on the line are few; 10 or 12 miles apart is near enough in a long line. The testing balls should be placed near towns not having offices, and at the posting stages, rather than in out-of-the-way places. One of these testing balls should always be erected on one or both sides of every large river span, but is not necessary at cable crossings, as the wire may be disconnected at the junction with the cable. At river spans, as the land line and crossing wire must be stopped, if a separate insulator be used for the line on each side, then a pair of platinum contacts may be used between the insulators to bridge the interval. When extra strength is required in the insulator two insulators may be placed in the alignment and coupled together by wire or a clamp; this arrangement is often used at very long spans, the coupled insulators at the terminals are placed to project above the top of the pole, it is useful when large insulators are not at hand; but care should be taken to so couple the insulators that they act together to resist the load. At terminals, unless otherwise provided for by cam or wedge fittings to the insulators, the wire is best secured by making a ring to pass round the head or neck of the insulator. In general, whenever the insulator has to bear a transverse load, it should be, together with the post, *in* the angle formed by the wire, the neck or head of the insulator and not the lugs or projections on it carrying the load directly. Insulator stalks should fit bracket sockets tightly enough to prevent shaking, or the porcelain may be cracked; the bracket socket and the insulator stalk should both therefore be slightly conical. One pattern insulator has the stalk fixed in the cups with tow dipped in a preservative, instead of being rigidly fixed by cement, to prevent fracture of the porcelain by expansion of the stalk or cement, or by shocks; in another pattern, a female screw socket having a solution of continuity in its circumference, is cemented into the porcelain, and the stalk is screwed in, the stalk not fitting tightly. The objection to the tow is the liability to shrink and decay, while the other mode of fixing is more expensive, and probably less efficient, than well-chosen cement, hence the use of cement is very general.

410. When, however, at a sharp angle the post cannot be placed in the angle made by the wire, if near a thoroughfare, a stout wire may be fixed to the pole above and below the insulator to serve as a guard to catch the wire in the event of it getting loose from the insulator; the necessity for a wire guard is exceptional, a single guard is sufficient for any number of wires on the same pole. For terminating the wire a class of insulator termed a shackle is frequently employed; these are much used in town lines in Europe for terminating overhead lines at offices, and for angles at which it is desirable to terminate the wire; they serve as testing or control insulators, but being inferior in the insulating property to ordinary insulators, and more expensive, they are more usually employed on short lines, and then as seldom as possible. The best pattern is that in which a double bell of porcelain is fixed between two plates of iron by a bolt passed through its axis; the wire is fastened round the neck of porcelain between the bells, these latter serving as rain caps. The mechanical conditions in the shackle are better than in the ordinary insulator, but as already explained, the latter should be preferred when practicable. At offices when a shackle is used to obtain a solution of continuity in the conductor, two porcelain double bells are used. A very inferior form of shackle is one in which simple reels or drums of porcelain are substituted for the double bells; such shackles should not be used, as they are very imperfect insulators.

411. For aerial lines iron wire is used. In Europe No. 8 B.W.G., diameter ·17 inch or 4·31 millimètres, weighing 389 lbs. per mile, may be considered about the medium size employed; the largest size usually used is probably No. 4, diameter ·24 inch or 6·1 millimètres, weight 775 lbs. per mile; No. 3 is used occasionally. In India No. 1 was used, but its use has been discontinued, and most of it replaced by lighter wire, the standard size is 5½; No. 12 is the smallest size commonly used; No. 16 may be used for special purposes, but in short lengths, and very seldom. In America No. 9 is the commonest size, 7 and 8 are used, and 6 is used occasionally. In Prussia about No. 5½ is used for international lines; for ordinary lines about No. 8, and for leading in wires, crossing railways, &c., No. 11. The gauge of wire should be ruled by the number of wires on each pole, this is regulated in India as follows:—

2 wires on each pole, ...	No. 5½
3 to 6 ,, ,, ...	,, 9½
7 to 14 ,, ,, ...	,, 12½
More than 14 wires on each pole, . .	,, 15½

For town lines and long spans stranded wire is used; thin wire (unannealed) is stronger and more ductile for its weight than thick, stranded wire has a greater tensile strength and ductility than a solid wire of equal weight per unit of length; stranded wire is more flexible, and hence easier to work with, but it exposes greater surface to the air, hence it corrodes more rapidly in a corrosive atmosphere, and it is more expensive; for example, 7 wires of No. 14 would be about 12 per cent. lighter, and 5 per cent. stronger than a single wire of No. 4. The advantage of using stranded wire appears to consist in the possibility of using it harder than single wire, for thin wires if annealed thoroughly are not stronger than thick ones. Thin wire proportionately stronger than thick is mechanically more economical, but a certain absolute strength is necessary, therefore the thickness of the wire cannot be reduced below a certain point dependent on the conditions to which the line is to be subjected. For railway crossings thin wire should be used, as not likely to cause accidents to rolling stock if it should fall across the rails; for lines to resist the severe storms of tropical countries, or accumulations of icicles on the wire, large sized wire is used; when many wires are to be placed on the same poles lighter wire is used, and the poles are nearer together; lighter wires are used in towns and across roads having much traffic than in the country and off-roads—the greater load on the thick wires and the greater weight of the wire, making an accident more serious to passengers the thicker the wire. When it is of importance to reduce the dip, as in crossing a wide river, stranded wire of steel is used; steel wire is much more expensive than iron, costing upwards of 100 per cent. more, but it is cheaper to use this wire to gain an additional 8 or 10 feet at a crossing, than to lengthen the masts by this additional height. Stranded wire is made of three, four, or seven strand wires; the wire commonly used for town lines has usually three strands, sometimes four; wire used for long spans has usually seven strands. Much wire used as iron is probably a homogeneous metal—*i. e.*, it contains more than ·25 per cent. of carbon, this being due to the difficulty of working up to the stringent conditions often imposed by the specifications. As the galvanising is rapidly dissolved by sulphurous vapours, in the neighbourhood of factories where much coal is burnt, and on railways, particularly in tunnels where the wire is much exposed to vapour and products of combustion from locomotives, the wire may be thicker than where not exposed to such agencies. As far as possible, the gauge of wire on each section of line should be uniform, as on uniform gauge lines the positions of faults can be more readily calculated from electrical measure-

ments. The best quality wire should be used, it should be as a rule soft, particularly if it is to be joined by twisted joints; if hard or of bad quality it is more difficult to manipulate, and causes waste of time and wire, and short pieces cut from the line wire cannot be used to make ties. The Prussian specification for wire specifies—the wire to be subjected to 20 rectangular bends before breaking, it may be wound several times round a wire of its own size in a close helical coil without breaking, splitting, or springing back, it must carry 2204 lbs. (English) per square inch tension for a quarter of an hour without stretching. The wire is almost invariably galvanised, but sometimes it is varnished, varnishing being less expensive. No. 8 and smaller sizes are best joined by a twisted or bell-hanger's joint, larger sizes by a Britannia joint. The twisted joint is made by holding the wires together in a hand vice, clip, or pliers, and twisting each three or four times round the other as closely and as tightly as possible with an eye-bolt; a special tool, termed a joint lever, is frequently used for making these joints. The Britannia joint is made by placing the two wires made quite straight together for about 18 inches, or for the thickest wires 2 feet, and fixing them with a vice, clip, or eye-bolt; a serving of thin wire, usually No. 16 B.W.G., from 2 to 4 inches long, is put on in the centre of the double wire, the free end of wire on each side of the serving is bent to an acute angle, and the ends of the thin wire served tightly round the main wire on each side, the ends of the thick and thin wires are cut off close. The binding wire should be of the best charcoal iron, and it is much better and quicker served on with a mallet; if it be put on by hand it is likely to give slightly and crack the solder if soldered, or even to open out. In India a special tool is sometimes used, and in England a joint-hook is used to bend up the line wire; the first is a very special tool, and neither are absolutely necessary. Sometimes wires are twisted together before galvanising, and the zinc coating is relied on for continuity of electrical conductivity; this kind of joint should be avoided, joints should be invariably soldered with tin solder. On temporary lines the joints are not usually soldered, but on permanent lines they should invariably be soldered to ensure electrical continuity. The malleability, tensile strength, and resistance to shearing of the solder is very different from that of the iron, hence it is only in very thin wires that the solder can be relied on to hold the joint, and it is only in such the solder should be suffered to bear the stress (*vide* Soldering). Several other modes of joining wires have been proposed and applied; amongst others a tube has been substituted for the wire serving, the wire being held by hooks

or wedges; but the thin wire serving is generally used, and is preferable, as it is less likely to permit sliding and consequent cracking of the solder. If the resistance of the solder to shearing be alone relied on, with soft iron wire the section of solder exposed to shearing stress should be at least ten and a half times the area of the cross section of the iron wire. When line wires are not continuous, as when the wire is wound on winding drums, shackles, or even when the ends of the wire are on the same insulator but not actually joined, a thin wire (No. 12 to 16) is wound into a spiral, and soldered to the line by its ends to ensure perfect electrical continuity. When the wire is bound to every insulator, the commonest practice at present, this is done in several ways; one method and that most generally employed, is to use No. 12 to 16 wire, wind it round the insulator in a form dependent on the pattern of the insulator, bind it for four turns tightly round the line wire on each side of the insulator, twist its ends together, cut them short, and turn them down; the wire will not run if well bound, and a breakage of the heavy wire used in India erected on 16 to 18 feet poles is found to produce merely inclination of three to five poles on each side of the breakage. When many wires have to be erected across a long span they are best made into a cable, the cable is suspended from two iron wires, as it is deficient in tenacity. For the cable copper wire well insulated with gutta-percha or India-rubber should be used; in tropical countries the latter should be preferred, and the whole should be taped and tarred, or if of India-rubber covered with felt. A cable such as above described is the most economical mode of crossing a wide river with many wires, as by other means it is difficult in this case to prevent contacts without great additional expense. If several lines on the same pole be of equal importance, then the heaviest wires should be placed on the lowest insulators; but the most important lines (generally the thickest wire) should always be placed above, being then less liable to accident. Local lines should evidently be placed below. The lines should maintain the same order of arrangement on the poles along the entire route, and the more important wires should be placed on the side of the post nearer to the road, canal, or other line of communication adjacent.

412. Iron poles do not require to be protected by lightning rods, but wooden poles and the insulators on them do require such protection. Iron poles are usually surmounted by lightning spikes; these give the post a more elegant and finished appearance, but are not necessary to protect the post. When, however, insulators are placed on the tops of iron poles, a wire, preferably

pointed, should be connected metallically with each pole, and extended for a short distance above the insulator, as insulators so placed are liable to have their tops shattered by lightning. The lightning does not escape from the edge of the iron hood to the pole, but entirely destroys and removes the top of the insulator, leaving the stalk exposed above; this has been observed frequently in India. That the damage is due to lightning is proved by the burnt appearance of the damaged insulator, and by the fact that several insulators on contiguous poles are usually destroyed at the same time. Wooden poles should as a rule have lightning rods, particularly across open country; if they have metal stays or ties, only the part above the tie need be protected. Lightning rods are usually of stout wire, stapled or nailed to the pole from end to end. In India the use of staples or nails in fixing lightning and contact wires to wooden poles has been discontinued, as it was found the lightning discharged by the points and split the poles. Wooden poles are usually fitted with rain-caps or roofs of iron or zinc, to increase their durability; the caps are sometimes surmounted by lightning spikes, or the lightning rod may be continued for a short distance above the pole; caps and brackets should be attached metallically to the lightning rod. The lightning rods should be either all placed on the same side of the poles, or preferably on the side most exposed to view during inspection. It is not necessary to solder the joint between the lightning wire and the cap, but the connection between the brackets and the discharger should be soldered, as the object is to carry off leakage currents, which might otherwise interfere with the traffic on the lines. Multiple lines on wooden poles need contact wires when lightning rods are not used, but the lightning rod, when present, should be made to serve both purposes. Contact wires are usually of thin wire (12 to 16); they should be soldered to the brackets if the latter be of metal, and connected through the ties or directly, to the earth—they should be placed as described for lightning wires. Sometimes lightning rods are only used at every alternate post or at longer intervals; as when posts are destroyed by lightning several contiguous poles are usually destroyed at the same moment (in India commonly four or five, and occasionally as many as twenty), lightning rods at intervals may often prove sufficient; but for half a mile on each side of offices and cable houses, on high ground, and when tall poles are used, every pole should have a rod. Masts should have rods to protect that part of their length not protected by metal stays, and should, if practicable, be surmounted by spikes. Telegraph buildings should as a rule be protected, as protectors can be made of old waste or spare wire at a very

trifling cost. To protect a pole or building the rod should be higher or as high as the structure, connected metallically with all metal parts on its surface, in good contact with the earth by being immersed at one end in a well or sunk to moist earth, and of ample electrical conductive capacity.

413. Wire, brackets, bolts, insulator hoods, poles, &c., of iron are usually galvanised; sometimes black varnish, or a varnish coat given by immersing the iron in hot drying oil, is used as a preservative instead of galvanising; but these require renewal from time to time, and although cheaper in first cost galvanising is more economical in use, and should be preferred. When exposed to sulphurous acid, as near furnaces, or to muriatic acid as in the neighbourhood of the sea, lead paint, any anticorrosive paint, hot oil, or oil and tar, may be used to protect the metal; but it should be done inside and out, and as far as practicable renewed from time to time as it wears off.

414. In railway tunnels and underground passages generally, such as the sewers and catacombs of Paris, telegraph wires may be erected on the walls on ordinary insulators fixed to the walls directly or by brackets, or covered wires fixed along the walls may be used. The covered wires may be coated with gutta-percha or vulcanised India-rubber, and covered with felt or tape soaked in Stockholm tar, or of gutta-percha covered with lead. Gutta-percha covered wire taped and tarred, is frequently used; it is cheaper than lead-covered wire, but inferior in durability, and in tropical climates seldom admissible. Gutta-percha covered wire protected by being enclosed in a tube of lead is exceedingly durable, and most economical in use, particularly when products of combustion of coal are present in considerable quantities in the atmosphere. In towns underground wires are used. They are employed to a greater extent in London than elsewhere. Being in short lengths, the induction due to their close proximity to each other does not impair their electrical efficiency, the insulation is higher, as exposed insulators cannot be kept clean, and there are obvious advantages in employing underground wires in towns when the number of wires is very numerous. If there be no danger of the earth being disturbed, and but few wires be required, as in many Indian towns, then simple gutta-percha covered wire protected by lead may be used; but as this wire will not resist rough usage it should not be used in any place where the ground is likely to be disturbed to repair water, gas, or drain pipes, hence it cannot be safely used in large European towns. As a rule underground wires are protected by tubing of some kind; sometimes wooden troughs are employed, the covered wires being laid in the trough, a wooden cover is fixed on and the pit

covered in. Cast-iron tubing is generally employed to protect underground wires, the system being modified accordingly as the number of wires to be laid is large or small. When the number of wires is small the following is a good system:—The tubes used are those made for conducting gas, &c., they are laid in straight lines joined by elbows; at intervals of 50 to 100 yards the segments are connected by short lengths of tubing of larger size, the gauge of the connecting piece permitting it to slide on the tubes it connects, the tubes are carefully laid; the connecting pieces being left open, a string is passed through each tube as it is laid, as each segment of 50 to 100 yards is completed a cord is drawn through it, and by means of this cord is drawn in the covered wires, the connecting tubes are drawn over the intervals between the segments, and the joint is made tight with lead. The route of the wires is carefully surveyed and drawn, the positions of the joints being marked on the plan; hence, if repairs become necessary any joint can be found readily, bad pieces of wire tested, removed, and good wire substituted, without disturbing the earth and tubes elsewhere than at the joints. The tubes are hermetically sealed, the wire is usually covered with gutta-percha, taped, and tarred; the wires are very durable even when the surrounding earth is impregnated with illuminating gas, which would injure the gutta-percha if unprotected by the tubing. Sometimes instead of single wires, cables containing several wires up to as many as ten are used; the advantage of using a cable consists in the saving of space, but when practicable it is better to use single wires. Sometimes the wires are fastened together to form a bundle; but the best mode is probably to tie them together at intervals, and as they are drawn into the tube remove the tying, there is then no danger of a wire rising and sticking in the tube; and should any wire fail afterwards, it can be removed without disturbing the others. At the junctions of the segments of tubing the wires should be numbered. When a great many wires are required, the system is only varied from that described above in a provision for gaining access to the wires without disturbing the earth; it is evident as the number of wires is increased the necessity for ready access to them becomes greater. The tubes are of course large enough to contain the required number of wires, they are not connected by joints, as described above, but are left disconnected and separated by a short distance, the ends of the tube opening into a box of cast iron or a pit lined with masonry or other suitable material intersecting the axis of the tube; this box is covered by a movable cast-iron cover, the upper surface of which is level with the pavement. Large pipes of cast iron are sometimes caulked at

the joints with tarred yarn instead of lead, the admission of water being favourable to preservation of the gutta-percha. Sometimes stoneware pipes are used—they are caulked at the joints with Stourbridge clay. Although the admission of water to the pipes is beneficial, the caulking must not be of a kind permitting earth or sand to enter the pipes. Lead piping may be used when stoneware is not available in situations where iron would be rapidly corroded. Access to the wires is obtained by lifting the cover off the pit or box, when the wires are seen within. Sometimes short hollow posts are erected instead of the box or pit above described, the wires being brought up into the post, which has a small door or lid through which access may be obtained to them. Plans should be kept of the routes, positions of draw boxes and posts, &c. Draw boxes appear to be superseding draw posts, they are evidently easier to construct, cheaper, and they do not obstruct the thoroughfares as the posts do. Copper wire is used as the conductor, it is commonly No. 18 B.W.G. and covered to No. 7 B.W.G. with two layers of gutta-percha alternating with two layers of Chatterton's compound, it is usually in lengths of 400 yards. It is evident the tubes are not hermetically sealed, and the wires cannot be expected to last so long, while the depth to which the tubes are buried is less than in the other system; working draw boxes may be 2 to 3 feet long, or longer according to necessity, but should not be larger than necessary for the purpose required. When merely for drawing the wires into and out of the tubes the boxes may be very small, not much exceeding in diameter twice the diameter of the tube; these boxes may be sealed with asphalt or covered with earth, and opened when necessary. The tubes may be buried about 2 feet deep, iron pipes are commonly laid 1 foot deep. The distances between the draw boxes vary with the nature of the line; on a straight line they may be longer than on a line having many angles, and it is obvious they should, when practicable, be so distributed as to be placed at angles and on curves. The standard distance should depend on the strength of the wire, and whether it is required to draw in and out single wires or bundles, as when single wires are drawn from amongst many others the friction is considerable, particularly when the wires are covered with tape and have rough surfaces; when the wires are numerous, probably 100 yards should not be exceeded between draw boxes or posts ordinarily, but these draw boxes need be only just large enough to allow the wires to be drawn, larger boxes for testing, &c., being placed at intervals of 400 or 500 yards to contain all the joints of the core. The commonest form of joint box in use in England is 2 feet 6 inches long, 1 foot

deep, and 11 inches wide; the pipes project a very short distance into the joint boxes. Boxes are placed at least every 200 yards; a box is placed every 400 yards to enclose the wire joints, and when the route is curved additional boxes are used as necessary for drawing in the wires. In all cases the wires should be numbered or lettered at each draw box or post, and the draw boxes or posts should be numbered. Closed systems of pipes may be placed 3 or 4 feet deep with advantage, but need not be laid so deep. The covered wires used for subterranean lines are joined in the manner proper to the kind of core used; lead-coated covered wire is firstly joined in the usual manner, and the lead coatings joined by very fusible solder, or covered with sheet lead, and the joints varnished to seal them. The wires used are sometimes stranded, but single wire is generally used—it serves the purpose, and should be preferred as a rule; the joints used for the conductor are the twisted joint, and solder is used invariably. The use of cement and asphaltic mastic for underground wires has been already referred to (Paragraph 277); covered wires in wooden tubes, surrounded by asphaltic mortar, form probably the best lines after the systems with iron tubes, and under some circumstances may be employed. When test boxes are used, as the wires are exposed to the air it is no advantage to close the joints of the tubes hermetically, but lead should be preferred to tarred yarn for joints in iron pipes, as caulking of yarn may decay, and the earth may be washed into the tubes. Probably stoneware offers advantages over cast iron as a material for pipes, being indestructible and having a smooth inner surface; it might also be fashioned into test boxes, a mere lid to the pipe being sufficient. The common pottery ware of India, thick and well burnt, if laid in asphaltic or cement mortar, would form a very cheap and durable receptacle for subterranean wires. Clay puddle might be substituted for the mortar if desirable to reduce the first cost. The use of naked wires in asphaltic mortar, and of calcareous cement as an envelope for wires, is referred to in Paragraph 277. Buried wires are much more expensive to lay than overground lines are to erect, hence the latter should be preferred when admissible. If sewers, tunnels, or other suitable underground ways are available, town lines should be laid in them, as cheap, open to inspection, and safe. When only very few wires are required in places where the soil is not liable to disturbance, and does not contain corrosive substances, simple lead-coated wire may be used placed 3 or 4 feet deep. Underground wires are used almost exclusively in towns, hence they usually terminate in offices, and are seldom joined directly to overhead lines; they are protected by lightning dischargers, as

usual with all lines in offices. When, however, it is necessary to join overhead and underground wires, this should be done in a hollow column bearing the overhead wires in a draw box or other receptacle, and a lightning protector should be interposed. Underground lines are not liable to electrical disturbances to the same extent as overground lines, but if connected with overground lines they are exposed to injury during thunderstorms, and hence should be protected. In laying subterranean tubes to contain wires the bottom of the trench should be levelled and so consolidated, if necessary, that there may be no risk of it sinking unequally, by which the pipes might be bent or broken and the joints forced open.

415. In towns having several offices, one office only should correspond directly with foreign and provincial offices; this office should be as central as practicable, and the town lines should form a purely local system, communicating with other towns through the central office only. The local lines in this case being so short, are readily inspected and repaired, are not required to be so perfect electrically, and hence it happens that an economy may be practised on such lines which would be absolutely inadmissible on long lines.

416. The construction of masts is treated in Part II., chapter i., section 1, division 2, and Chapter II., section i, division 2. When of wood, care should be taken to seek native timber rather than import foreign; if iron masts are to be used, care should be taken before adopting any peculiar pattern put forward as possessing special mechanical excellence, to examine it by the light of the mechanical principles involved in the correct forms of beams, and an ordinary post of the proposed pattern should, if practicable, be tested for transverse strength. The various means of protecting wooden structures from the attacks of insects and decay, as coating the base with metal, tarring, painting, &c., should be considered and suitable measures adopted; by such means, when heavy first cost has to be avoided, wood may be used instead of iron.

417. In most cases rivers are crossed with strong cable, particularly when the bed of the river is likely to scour. Pieces of old cable should always be regarded with suspicion, and only employed after careful examination; the fact of former failure must be regarded in considering the suitability of the cable for its new situation—*e.g.*, a cable which has been broken through being too weak to resist a rapid current, may be quite strong enough for another stream having a soft bottom and slow current. Cables on rivers often have to be laid in a very primitive manner, being merely payed out by hand; although a little cable is thus

lost, the cost is much less than if a special boat and appliances were sent for the purpose, while the looseness of the cable is usually a great advantage, allowing for scouring of bed and banks, for repairs, and making it easier to lift the cable if necessary. A rope stopper should be kept round the cable ready to stop it at any moment, the boat should be a strong one, as its steering is interfered with by the cable as much way should be put on it as possible, and by having a large crew provision should be made to manœuvre the boat quickly. Two flags should be put up on each bank, and floating bodies should be used, if the river be wide, to mark the line to be taken; the boat is kept in this line, the head boatman is probably the best man to steer, and a good plan is to take the boat over the course once as a trial trip, particularly when there is a strong current. A second boat should be engaged as a rule, particularly when the current is strong. Cables are laid in the sea by special machinery described elsewhere; short cables across straits and arms of the sea have often to be laid from ordinary vessels without special machinery, and in this case the resources at command have to be made the most of, but in such cases the cable is usually laid more slack than when proper brakes are used.

418. The tools for constructing telegraphs should usually be of very good quality; as carriage is frequently expensive, there may be difficulty in getting tools well repaired, if the tools be not of good quality a considerable reserve is necessary to prevent men losing time waiting for tools, and to ensure that no delay may occur in the execution of the work when once commenced. The subject of tools is treated in Part II., chapter iv., section 2. Economy in tools may be attained by dispensing with some tools frequently considered necessary, making others on the spot employing native mechanics when necessary, and preferring tools of a kind likely to be of use for maintenance purposes afterwards —*e.g.*, for digging holes, as only one man can work in a hole shovels and spades need not both be provided, the latter are sufficient; ladders and shear legs may be made, hired, or purchased where required, and returned, sold, or burnt when done with; rammers are heavy and often readily made as required, and they may be used as fuel when broken. By such means there is great economy in carriage and frequently in cost of the articles; in India native-made tools are frequently purchased, or made by village workmen to order as required, they sometimes cost less and are more suitable than imported tools. If many sizes of spanners are required, they may be replaced by an adjustable spanner, which is very useful afterwards. All the tools should be of strong and somewhat heavy patterns. A

reserve of tools, particularly felling and jungle-cutting tools, should be provided; the patterns of these should be, as far as practicable, such as may be readily repaired locally if broken, and as simple and few in number as consistent with good and rapid execution of the work. Skilled mechanics require many and delicate tools, but the majority of men employed in telegraph construction are not highly skilled, hence the tools should as a rule be such as will resist the effects of rather rough usage. The patterns of the country, when peculiar, should be adopted if practicable; tools used by weak differ from those used by more stalwart races of men, and this should be considered—*e.g.*, the native of India has not as a rule sufficient strength to wield effectively the broad axes used by Europeans; the native axe is narrow and stronger at the edge, it does less work at a stroke, but a native will generally do much more work with it than he could do with the European instrument in the same time, his first attempts to use the latter often result in its edge being either turned or badly chipped.

419. The expense of constructing a line will depend greatly on the degree in which local labour and resources are employed by the engineer, and the efficiency of organisation of labour and supervision. Each supervisor of labour should have as many labourers under him as he can efficiently supervise, and the engineer in charge of the whole work should in turn have as many working parties at work as he can profitably employ, thus diminishing as far as possible the cost of supervision. If shelter for the men can be obtained along the route tents may be dispensed with, but then each move forward should be made to a village or town affording shelter—this applies to countries less covered with communications, and as a rule of larger extent than England. In a country like India there is less time lost when the men live under canvas than when they lodge in villages. The most reliable materials of construction are usually also the most economical; if it be desired to reduce the first cost of a line, this end should not be attained by using inferior qualities of wire, insulators, brackets, &c., such saving would be more than counterbalanced by greater cost of maintenance and commercial depreciation consequent on uncertainty of communication; the saving should be effected by using stones for anchors, making stays and ties of spare wire, omitting the clips, straining screws, cross feet or earth plates, stretching insulators, extra strong angle posts, &c.; when practicable, by using wood rather than iron for poles when on calculations, as already explained, its use is admissible, and generally by sacrificing appearance and convenience, while maintaining the highest degree of permanence attainable,

by adopting throughout the strongest forms, justest proportions, and best qualities of materials. In some cases it is possible to reduce the cost of a line by aiming only at the minimum of electrical efficiency admissible, as when single bell insulators are used in towns for local wires; in other cases an inferior degree of mechanical excellence is admissible, as when weak poles are used with light wires, or low poles are used inside a railway fence.

SECTION II.—*Estimating.*

420. The term *estimate* in its limited and strict acceptation is applied to a statement of the quantities of the work to be done, the labour necessary to do it, and the cost of the labour, carriage, and materials; but in a more extended sense the term is often applied to a document composed of three parts, termed respectively the *report*, *specification*, and *estimate* proper. In some cases a report may be required without specification and estimate, to admit of an opinion being formed on the necessity or practicability of the proposed work; or a specification only may be required, as when work has to be executed by contract, in which case the calculation of details of quantities and cost of labour, materials, &c., may be the business of the contractor, the specification merely fixing the nature, quality, and quantity of the whole work contracted for.

421. A report should state clearly according to requirements the object of the work proposed, the necessity or advisability of its execution, the chances of its success mechanically, electrically, or commercially as requisite, the circumstances of its projection, the reasons for selecting one route rather than another, one mode or form of construction in preference to others, general considerations likely to affect the cost of the work and of its maintenance, the obstacles or difficulties to overcome and the manner they are to be dealt with, a general statement of the extent and nature of the work, and generally all such particulars as are necessary to enable a judgment to be formed of its general utility and necessity, and of the efficiency and economy of the design and proposed manner of execution. When for the information of the public, or unaccompanied by a specification and estimate, a report may contain numerical statements which properly belong to the specification and estimate, such statements, when essential to the matter of the report, are then properly inserted. A reconnoissance or preliminary survey is necessary on which to found a report, and the latter should be illustrated by plans or maps if necessary.

422. A specification for telegraph work may be divided under

five headings—viz., materials or stores to be used, the carriage of these to the depôts along the route selected for the line, their distribution from the depôts, the work of construction, and the superintendence, including the supervision, designing of the work, &c. If the work under any one of the above headings is to be done by contract, then an extract from the general specification is used as a basis for the contract, with the addition of stipulations limiting the time to be allowed for performance of the contract, and the rates to be paid. When an expensive work, as an underground line, a cable, or a long span on tall masts, occurs on a line, these should be specified and estimated for separately, their cost being entered in the abstract statement of the cost of the whole line. In specifying stores to be used they should be carefully described thus—the kinds of posts to be used, their heights, the brackets, ties, straining screws, collars, insulators, gauges of wires, kind of joint to be used for wire, &c.; for underground wires, the kind of covered wire, the pipes, test and draw boxes, lightning dischargers, &c.; for cables, description of cable to be used, junction houses, lightning protectors, junction with land line, &c.; for long spans, kind of masts, their heights, number of stays, distances of anchors from masts, distance of terminal posts and junctions with land line, &c. The tests of mechanical and electrical efficiency which the several articles ought to stand should be stated, particularly in a specification to form the basis of a contract with a manufacturer or merchant —*e. g.*, wooden posts should have a minimum diameter stated for each end, for iron posts a minimum transverse strength and stiffness should be stipulated for; this may be measured by a horizontal force applied to the post 16 feet from the ground. The wire should be tested for tensile strength and ductility, and its galvanising may be tested by immersion in sulphate of copper solution; insulators may be tested by steady strain, and by a shock; brackets of cast iron and malleable cast iron may be tried with a hammer, &c. The working load to be permitted on wire, posts, and insulators should be always stated, for the information of the officer entrusted with the execution of the work. Excellence of quality in materials may be ensured by specifying the kind of raw material to be employed, and placing restrictions on the mode of manufacture; thus, charcoal iron, malleable cast iron, steel, best qualities of copper, silver solder, fine quality porcelain, &c., may be prescribed. It may be stipulated that wire be drawn through a minimum number of holes, that it be not welded in process of manufacture, and be in lengths of a minimum weight; that covered wire have a minimum number of layers of the insulating material; that insulators be moulded by

pressure, &c. The design of the structure should be specified thus—the number of posts per mile, the number and gauge of the wires, the average number of ties and road crossings per mile, the tension and dip of the wires, the minimum distance between them, the minimum distance to be allowed between the wires and adjacent objects, particularly trees and jungle, and between the wire and the earth; the sharpest angle to be made, the minimum height of road and railway crossings, the number and sites of testing balls, or test or control posts; the number of terminal posts and the conditions of their employment, mode of fixing or tying the wire to the insulators, &c. For wooden poles, the description of lightning rod and manner of its attachment to the pole should be stated; for cables, the length of cable; for masts, the height of the masts, dip of wire, and height of wire above tallest vessel at high flood level; and for underground lines, their length, the average number of test posts or boxes per mile, should be specified. The sources from which the stores are to be obtained should be specified—as purchased locally, made as required, to be supplied by certain manufacturers, removed from an old line, &c. The mode of conveyance, and the names and situations of the places from which the stores are to be distributed, should be stated. Package and terminal charges may be included as contingent on carriage. Under the heading DISTRIBUTION should be described the means to be employed for conveying the stores from the depôts to the work; under the heading LABOUR should be stated the sources from which the labourers are to be obtained; and under the heading SUPERINTENDENCE should be stated the number of persons, and the names of the principals to superintend the work, with an approximate statement of the time to be occupied in executing it.

423. The estimate proper is a numerical statement of the quantities of stores, carriage, labour, and superintendence necessary, and their respective costs. Full details should be entered shewing the quantity and cost of each description of labour, material, carriage, &c., to admit of accuracy and economy being checked, to shew the grounds on which the result has been arrived at, and to furnish the engineer entrusted with the execution of the work with a means of checking his expenditure by the estimate. As with a specification so with an estimate, a partial estimate only may be required to be furnished by a particular person, and the complete estimate may be made up of several partial estimates, each by a different person—*e. g.*, a manufacturer may be required to furnish an estimate of the quantities of stores, their weight and price; a contractor for carriage being furnished with the dimensions and weights shewn in a manufacturer's estimate,

may be required to furnish an estimate of the cost of transport or distribution; and the labour may be estimated for by the engineer to be entrusted with the work—an abstract of the several partial estimates exhibits the total cost of the line. It frequently happens in large companies and government departments, that one officer purchases material and is entrusted with its custody, while another designs and executes the work of construction; in such cases it is obvious estimates are properly framed in two parts—one part relating only to the cost of the stores being framed by the officer who has charge of the stores, the other part being framed by the officer entrusted with the execution of the work. In this case the latter part is framed first, and on the data supplied therein the other part is framed, and its total amount is entered as a separate item in an abstract. The cost of stores is fixed by the manufacturers' rates, and may be known exactly; but the cost of carriage, labour, and superintendence will depend in a great measure on the industry, knowledge, and judgment displayed by those entrusted with the execution of the work. Therefore, to afford a check on the execution of the work, the cost of the stores should form a distinct part of the estimate, which part may be used as a check on the manufacturer.

424. Under the heading of *stores* or *materials*, including tools, should be entered the designation and weight of each article, the price being entered as explained above, the number of articles of each kind per mile, the total number required, and their total weight. Such articles as tools are not always calculated on the mileage, but frequently according to the number of working parties or men to be employed during the same time. Special articles, as terminal posts, testing balls, surveying instruments, &c., are merely entered with remarks, or the specification may be referred to; paint, tar, &c., are calculated on the 100 square feet of surface, or more conveniently when for poles by the quantity required for each pole. When timber poles are used the number of cubic feet in each pole may be shewn. A small excess is allowed over the calculated quantities to allow for unforeseen requirements, breakage, and to form a reserve for repairs. The percentage allowed in excess of calculated requirements should be shewn in the estimate in each case; it will evidently vary according to the nature of the material and the circumstances of the particular case—*e. g.*, a large percentage of insulators may be allowed, but a smaller percentage of poles; if the number of poles and length of the line be known exactly, the excess may be less than if the line be only measured approximately, as when a road or railway mileage is made the basis of the estimate for the telegraph line. In towns

the telegraph route should be marked out on a plan before framing the estimate, and rivers should be surveyed before estimating for cables or long air spans. Ordinarily 5 per cent. of insulators may be safely allowed in excess, but $2\frac{1}{2}$ per cent. of wire and a still smaller percentage of poles will generally be found sufficient. Some articles, as fuel for making joints, are usually purchased as required; stores to be so purchased should appear in the estimate under a separate heading. Some articles, as angle-pole ties, can only be estimated for approximately, unless the line has been actually marked out before framing the estimate; such should be taken at an average per mile—*e.g.*, two angles per mile may be considered an average on a road line on level country when the road winds but slightly, and the line may be placed on adjacent land.

425. In estimating transport of materials, water carriage is generally the cheapest, railway cheaper than road, and wheeled carriage on roads cheaper than animal carriage; carriage by men is very costly, the labour is difficult to obtain in sufficient quantity, and its employment necessitates costly superintendence, it should be therefore avoided as much as possible. Railway carriage is the quickest, and in some cases may be therefore preferred; bullocks are slower than horses, but in many countries their labour is cheaper, because they are more hardy, cheaper to purchase and to feed, and they require less attendance. Carriage by elephants and camels is exceptional; the former is always more expensive than bullock carriage, the latter is adapted to peculiar conditions only. The several means of transport adopted should be distinguished in the estimate, the total mileage, the total weight carried, and by land the rate per ton per mile should be shewn. In the case of carriage by sea, the termini, the rate per ton, the total weight carried, and the total cost of carriage should be shewn. When carriage by men or animals is employed it is convenient to adopt a smaller unit than the ton, in this case the rate per hundredweight or per thousand pounds per mile may be shewn. In the estimate of transport must be shewn the terminal charges—*i. e.*, such as loading and unloading waggons or ships, cartage to railway stations or docks, stacking the stores, &c.; these may be conveniently entered at a certain percentage on the freight. Packing charges when necessary should also be estimated. The cost of distributing stores may be estimated separately for each section from depôt to depôt; the number of miles to be travelled in distributing may be calculated by the formula for the sum of an arithmetical progression; as the waggons or other means of transport must return to the depôt empty, this must be considered in the calculation. Some-

times a lower rate of hire is paid for returning empty, but generally this has to be paid for at the full rate, as the carriage is hired by the time employed.

426. The rate of distribution as cost of carriage is conveniently shewn by stating the cost of carrying one ton one mile. The calculation is sufficiently accurate if the shortest distance from the depôt travelled by a loaded vehicle or animal be taken as the first term, and the longest distance travelled as the last term, the number of terms is the number of loads distributed from the depôt; the sum of the progression multiplied by the weight carried as a load expressed in terms of a ton, represents the number of tons which must be carried one mile, to equal the work of distribution. The rate per ton-mile is the sum of the cost of carrying a ton one mile, and the fractional cost allowed for the means of transport returning empty; and the total cost of the distribution is the cost of carriage per ton-mile, multiplied by the total number of ton-miles. As in the case of carriage, a smaller unit of weight than the ton may be adopted if desirable. From the above it will be seen that the calculation is based on a load, although the stores are deposited along the route in smaller quantities it is not necessary to consider less than a load in calculating the cost of distribution. When the means of transport is paid for by the day, the return journey being paid for at full rate, the cost per ton-mile is obtained by multiplying the cost of carriage of a ton one mile by two. Distribution is therefore shewn in the estimate by stating the names of the depôts, the distances between them, the means of transport adopted in each case, and the work of distribution expressed in tons carried one mile. The cost of carriage is shewn in the cost of conveying one ton one mile including return journeys, for each mode of transport employed; the total cost is shewn for each section between two depôts, and the sum of the costs of distribution over the several sections is the total cost of distribution. In an estimate for a single cable or river crossing, the heading *distribution* is of course omitted.

427. The LABOUR statement should state the quantities of each kind of work to be done, the quantity which each man can do in one day, the rate of wages per day per man for each description of labour, the total number of days' work of one man necessary to complete each description of work, the total cost of the labour in each case, and finally the total cost of the whole labour of all kinds required to construct the line. Earthwork may be estimated for by the cubic yard when the work to be done is digging a trench for tubes or the shore end of a cable, or forming an embankment for a junction house; but post holes are better

estimated for by the hole; this is more convenient, because a certain number of ordinary holes may be assigned to each man as a days' work. The erection of poles may be estimated for on the basis of a fraction of a days' work of one man necessary to erect one pole, this is shewn with the number of poles and the total number of days' work of one man required to erect them. The labour of erecting poles depends in a great measure on the diameter of the holes measured at right angles to the alignment; if the holes be bored, or only just wide enough to receive the base of the pole, a gang of twelve men can erect 60 to 80 16-feet poles per day; but if the holes be 3 feet square, and cross feet or base plates be used, the labour of placing the poles accurately in the alignment is considerable, and two poles per man is a good days' work—a gang of 10 men erecting 20 poles. The extra labour is absorbed in placing the posts correctly in the alignment, and in filling in and carefully ramming the large holes. If the earth be merely thrown into the holes, heaped up, and left to sink, being very little rammed, 30 posts may be erected in large holes by a gang of 10 men; but a strong wind before the ground has been consolidated by rain, throws the posts out of the vertical—this mode of construction should therefore be avoided. The labour of putting in anchors and erecting ties is about the same as for an equal number of poles with cross feet. The labour of laying tubes after digging the trench varies according to the system adopted. The wires are laid out on the ground by one or two men per wire, another gang of one or two men makes the joints, and a third gang of from four to eight men strains the wires and places them on the posts; more men are used when the wires are heavy than when they are light, and a good plan is to have a separate gang for each pair of wires. If the wires are tied to each insulator this is done by men following. The work is estimated for separately, as unrolling wire, making joints, straining wire, and binding insulators. The practice of construction differs very much, and in the erection of wire no general rule can be given for calculating the labour necessary—*e.g.*, on some lines stretching insulators are used, on others the line is fastened to every insulator; much of the labour is absorbed in carrying the tools, and a large number of wires may be erected proportionately cheaper than one or two. The labour at terminals is often considerable, an allowance must be made for this, and for fitting testing balls or other fittings in the line. The fitting of brackets to the poles forms a separate item, its amount must depend on the form of bracket employed and the manner of fitting it; when carpenters are employed for this work it is best done at the depôts, and the number of poles a carpenter can fit in a day may readily be ascer-

tained if not known. Carpenters and smiths required to repair tools, men required to clear jungle, and all other kinds of labour required, should be distinguished from each other in each case; and as a rule the quantity of work a man can perform in a day, the total to be done, and the total number of men required to do it, should be shewn. When the work cannot be expressed in this manner, as in clearing jungle, it is estimated for by the average number of men required to do it per mile of line. The number of workmen required for each kind of work having been shewn as described, an estimate of the cost of the necessary labour is merely a statement of the number of days' work to be done by each description of workman, as, carpenter, smith, labourer, &c.; the rates of wages per day, the total cost for each description of labour, and the total for the whole work. The average cost of labour per mile of line is also often stated. In order to estimate closely the cost of labour for a given work, experience is necessary both of the work and the particular class and nationality of workmen to be employed. Each administration and individual engineer has a different mode of executing the work, while the materials and tools differ widely in form, weight, and mode of application; thus, only very general instructions can be conveyed under this head, and it is only desired to convey a general idea of a system which has been found to work well in India.

428. The heading SUPERINTENDENCE needs but little explanation, it should include the wages and travelling expenses of all persons employed to direct and supervise the labour of others; but it is manifest that men employed to supervise gangs should themselves work, so far as consistent with efficiently supervising the men for whose work they are responsible.

429. Other headings than the above are added, or some of those given are omitted, according to requirements; the labour of masons, bricklayers, carpenters, and other skilled mechanics, when employed on considerable quantities, may be estimated for under a separate heading, but as a rule are entered under the heading of labour. The heading MISCELLANEOUS may be used to include charges not included under other headings, such as purchases of petty stores, wages of temporary clerks, &c.

430. After estimating as closely as the data will permit, a common practice is to add a percentage on the total amount so obtained to provide against unforeseen contingencies: 5 per cent. may be considered sufficient to allow on the cost of labour, transport, distribution, &c.; but as extra stores and tools are provided in the estimate, 1 per cent. to $2\frac{1}{2}$ per cent. is sufficient to allow for unforeseen requirements under this heading. When estimating labour, the distance over which the tools have to be

carried and the work is distributed must be considered and allowed for.

431. Repairs when extensive, and when their nature and extent are known, are estimated for in the same manner as new work. In estimates for slight repairs, the nature and extent of which are known only in a general way, the different kinds of work may be distinguished only as far as convenient, and estimated for in days' work or value of the work per mile—carriage, stores, supervision, &c., being estimated approximately for the whole, or by the mile. Estimates for costly works should state very fully every particular; for small works the estimate should be simple in form and brief. When a permanent establishment is engaged to repair lines, as is common in Europe, although the value of each little work cannot be estimated for, it is very desirable to check the value of the work done, to control expenditure, and to test the economy of the organisation; this may be done by estimating for the repairs on each section for one year in one estimate, sanctioning the expenditure on this estimate, and comparing the cost of the work with the estimated cost. It generally requires more experience to estimate closely for repairs than for new work, particularly when heavy jungle has to be cut; but with local experience an engineer can usually estimate very closely.

432. After completion of the work under an estimate, the engineer entrusted with its execution may submit a report in a somewhat similar form to that of the estimate, but only stating totals and results; the actual and estimated costs of the work are compared, explanation is given of excess or defect of the former as compared with the latter, and departures from the original design should be described and explained. If an estimate be well framed, the actual cost of the work should be slightly less than the estimate; but sometimes by judgment and extra zeal on the part of those entrusted to supervise and execute the work, a considerable saving on the estimated cost may be effected, as in estimating only ordinary conditions in these respects can be assumed. The system described above is in very general terms that employed in India; it has stood the test of experience; it gives the maximum control over both design and expenditure, with the minimum of obstructiveness; the estimate is short and concise in form, the system being regular, the estimates serve to check each other, and by their use the cost of work in every part of the country has been ascertained.

SECTION III.—*Construction of Land Lines.*

433. Before a line can be marked on the ground its mechanical details must be decided, as the dip of the wire, its minimum height above the earth, the heights of the posts, their transverse strength, the load on the wire, the number of posts per mile, the maximum and minimum distances from the road or railway, the maximum angle admissible, &c. One or two catenary curves cut in sheet metal or card should be provided, being calculated in accordance with the factor of safety and modulus of tenacity of the wire to be used. The operation of marking out the line is best performed by the engineer marking the sites for the angle pole and those poles the sites of which are fixed by the nature of the ground, river masts, and the terminals of cables; the sites of intermediate poles are marked by an assistant, the engineer making any alteration requisite; alteration is seldom necessary if the first operation has been well performed. To facilitate the work of the assistant, when two angle poles occur far apart the engineer should mark the site of one intermediate pole in addition to the angle poles; the assistant is not usually furnished with surveying instruments, excepting a tape or chain. In towns, particularly for underground lines, the whole work must be marked out by the engineer, at least on paper—this cannot be entrusted to an assistant. In crossing bridges, before any work is done the engineer in charge of the bridge should be consulted, especially if the ironwork or masonry of the bridge is to be interfered with. In towns care must be taken to ascertain the positions of gas and water pipes, sewers, &c. The principal faults to be avoided are—placing poles on low ground when the ground rises between them, so that the line is brought too near the ground, and placing poles on ground so much lower than that on each side that with the ordinary dip the low pole is superfluous. Taller poles than ordinary are frequently necessary near obstacles, as huts and walls, to keep the line clear. A pole is necessary on each side of a road or railway when the line crosses either of these, but the sites of these poles being fixed, the intervals must be so divided as to approximate to the standard spacing and distribute the poles as regularly as possible. When several angles occur near each other care should be taken to make them equal, or as nearly so as practicable. The number of angles in the line should be kept as small as possible without in any case exceeding the maximum angle admissible, hence very slight angles do not as a rule appear in a line well marked out, excepting when the alignment is fixed, as on railway

curves and in street lines. When huts, walls, and other obstacles occur in the alignment marked (as is common at railway stations), which may render high poles or other expensive measures necessary and interfere with rapid inspections, the ground should be examined to ascertain if the alignment can be changed to avoid the obstruction; if it cannot, a long pole close to the obstruction, or a short one on it, is necessary, and the spacing on each side must be altered accordingly. The greatest deviation from the standard distance, excepting at road crossings, is half a distance, and this is sufficiently divided when distributed over four spaces—*e. g.*, if circumstances render it necessary to place a pole at a point half the standard distance from the site selected for another pole, instead of placing two poles half a distance apart, and the poles on each side of these the correct standard distance, the sites already selected should be altered, and the half distance equally distributed over four distances, either by moving four poles forward, thus absorbing the half distance and saving a pole, or by moving four poles backward, placing them nearer together and using an extra pole; in the first case four distances would be increased each to nine-eighths, in the latter four distances would be decreased each to seven-eighths of the standard distance. The sites for the angles and fixed sites being marked, the sites for intermediate poles are marked, the angle pegs being afterwards moved if practicable to make the spacing correct. The engineer only marks the angles and fixed posts, the intermediate ground is measured and pegs or staves put in by assistants, the whole is examined, the position of every pole and differences of level being scrutinised by the engineer, who puts in pegs for anchors and alters the positions of pegs where necessary. At angles the common plane of the tie and pole should bisect the angle; the site for the anchor hole is best marked with the compass, it may, however, be marked with a string. The string is prepared as in fig. 80; it has knots at A, B, C, and D; AB and AC are equal to each other, and likewise CD and BD, AE is a piece of string tied to the knot at A; if A be placed against the pole peg, A C and A B be stretched in the alignment on each side, and if D be drawn so that CD, DB be tight, then AD marks the direction of the anchor; AE is drawn tightly and brought over D, and a

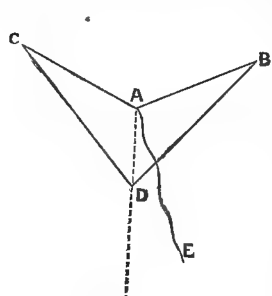


Fig. 80.

knot on E marks the centre of the anchor pit. Terminal poles when also angle poles usually have two ties, one on the opposite side to each line; but when the angle made by the lines is very obtuse these ties are insufficient; a tie in the line bisecting the angle must be used with or without the other two, as in practice the two ties described are found insufficient to keep the post perpendicular. At slight angles, if the ground be good ties are not necessary; but unless the ground be firm, even poles at very slight angles are drawn out of the perpendicular, and this gives the structure an unsightly appearance. By some engineers angle poles are not tied unless the force to which they are subjected surpasses their working load, but although there is a saving in first cost this is sometimes more than counterbalanced by the necessity for occasionally putting the poles again vertical, or the line becomes unsightly; it is as a rule better to tie every angle even on railway curves. When it is not possible to tie a pole from want of space, coupled or A poles may be used; but coupled poles are much more expensive than tied poles, and should therefore only be used when unavoidable. The pegs for coupled poles should be put in carefully, in order that the plane passing through the axis of the poles may bisect the angle made by the line. In pegging out a line the placing of the pegs must depend on the mode of construction to be adopted; if holes are to be bored and the poles put in without cross feet or earth plates, then a single peg may be placed for each pole, excepting at the angles, where two or more may be used. The holes for the intermediate posts are then all bored on the same side of each peg and in the alignment, or on the sites of the pegs; at the angles they are bored between the two or more pegs used, and the anchor hole is bored on one side of the anchor peg in the continuation of the line bisecting the angle. If the poles have earth plates or cross feet the holes have to be larger, and in long straight lines there is great difficulty in keeping to the alignment if the eye alone be trusted to; in this case a good plan is the following:—After the single peg marking the position of each pole has been put in, apply a gauge, shewn in fig. 81 AB to the peg at C, and put in a peg on each side through the holes A and B in the gauge, the gauge and centre peg is removed, and after the hole (shewn in the figure by the dotted line) has been dug, the gauge is again applied to the pegs A and B across the hole, the pole is then placed in the semi-circular notch of the gauge, as shewn in the figure C. The gauge may be made of a piece of board, or of stout wire bent to

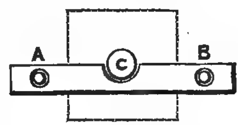


Fig. 81.

a proper form; it is better made of wood than of wire, but the latter is more generally available. When the holes are made long in the alignment, and not wider than the pole, a single peg is sufficient as when the holes are bored. On short pieces of straight line there is not much danger of the alignment being departed from, and the gauge is not necessary; but when long straight lines of holes have to be dug far in advance of the gang erecting the poles, the gauge is a necessity; generally less skilled labour is necessary, and the work is done more accurately and quicker when it is used. When there is difference in level, the properties of the catenary should be remembered in placing the poles; if a difference of level occurs abruptly, as when a pole is placed on a building, or a high pole is used to cross an obstruction, the low pole should not be placed nearer to the high one than the distance which gives no dip below the lower point of suspension, the curve being half a catenary; this distance should be calculated, and so increased that the dip below the lower point of suspension be equal to the standard dip. When a valley has to be crossed the dip of a line suspended over it should be calculated; or an elevation of the tall objects in the valley may be drawn to scale, and a curve of the line cut to scale being applied to this drawing, it will be at once apparent if it be necessary to place poles in the hollow, or if it be decided to place poles in the hollow it will be apparent if these poles should exceed the standard height. In general, hollows and hills should be regarded as advantageous, affording facilities for reducing the number of supports. A line raised by being traced from hill to hill may in some cases be raised above jungle and trees, thus saving the expenses of the first and the periodical clearings which, when through heavy jungle and wood, cause an enormous enhancement of the cost of construction and maintenance. Where a pole is on slightly lower ground than those on each side of it, it is sometimes lengthened, but this is not necessary excepting for appearance, as the effect of unequal height in the poles is to distribute merely the vertical load unequally, and although it is desirable to distribute this uniformly, such a small part of the working strength of the poles is used up that considerable inequality is admissible. In India, when erecting lines over uneven ground, the poles being 17 feet 6 inches in height, variations in height are obtained by placing the poles deeper to a maximum excess of 18 inches or less deep to a maximum defect of 1 foot, and by using poles varying in length to a maximum in general of 24 feet. On inclines and elsewhere when there is necessarily inequality in heights of poles, this may be taken advantage of to economise poles, excepting when an angle *must* be made near

a tall pole by reason of buildings or other obstructions occupying the ground. On inclined ground no attempt should be made to place the tops of the posts on the same level by the use of posts of unequal heights, this is expensive, unnecessary, and the use of poles the same length distributes the load most equally. On a regular incline the poles cannot be separated beyond the normal distance, as when abrupt differences occur in the levels of the ground; for if the poles were so placed that the wire in each span formed half a catenary, the bulging of that half below the line joining the points of suspension in a direction at right angles to that line, would be greater than the normal dip on horizontal ground, and hence the wire would be nearer the soil than the minimum distance; in these cases a curve, either in metal or card-board, drawn to rather a large scale, should be applied to a drawing of the ground, and the marking out done so as to place the poles at the maximum distance apart consistent with the minimum distance between the wire and the earth being maintained. In towns the lines are either taken underground in tubes or overground; in the former case the tubes usually follow the lines of the streets, and it is necessary to fix on positions for draw-boxes so that the wires may be got round corners without difficulty; in the latter case sometimes great difficulties are experienced. When the houses are of unequal heights and are many of them deficient in strength, as in Indian towns, the line has to be constructed on poles mostly of considerable height; the line should follow the lines of the streets that it may be readily inspected, but it should nowhere obstruct traffic. Overground town lines, when the buildings admit of it, are most economically constructed on the roofs of buildings; such lines have the advantages of not occupying the thoroughfares, being much shorter and less liable to accident than street lines, but they are more difficult to inspect. Such lines are best laid down provisionally on a plan of the town, then the marking out is done on inspection of the several points chosen for supports. When poles are erected on roofs they are usually shorter than those erected on the ground; they should be placed over a beam, a socket being first fixed to receive the pole, and the spot chosen should allow of the necessary stays having sufficient spread and proper points of attachment. The insulators may be supported on iron brackets bolted or let into walls or chimney stacks, unless the wires be very numerous; in London there are many poles erected on houses, in Paris brackets are fastened to the masonry—the latter system is more economica and safer when the lines are few. For town lines a system of squares or triangles is usually adopted when the lines are taken over the houses, such a system can only in part be adopted to

2 B

street lines. Lines in drains and other underground passages not constructed for the purpose, should be marked on a plan, and afterwards marked on the sites selected; in Paris the sewers and catacombs contain many of the town lines. In some parts of Prussia lines are suspended from living trees by means of a swinging insulator; fixed insulators may be spiked to living trees when lines have to be hurriedly constructed, as for military purposes. At a river, if the span be short, an air span should be preferred; in general, air spans should be preferred where practicable, cables being used only where necessary. When the current is slow, the bed and banks permanent and not rocky, there is no danger from traffic, and an air span would be very expensive or is impracticable—a cable is used. For an air span a narrow part of the stream should be chosen, the line should not cross obliquely, the level of the highest known flood should be inquired about, the usual height to which the river rises should be found, and the maximum height of the masts of boats or ships navigating the river should be noted. The masts may be erected on ground liable to inundation if on sites out of the current, particularly if the span may be decreased thereby; timber masts on such ground are safe from the attacks of white ants and some other destructive insects—pine and other soft wood is not attacked by white ants in India under these conditions. Stayed masts must not be placed in currents, as driftwood is liable to catch in the stays. When the stream is liable to great variations in current and level, as with rivers in tropical countries, it should be inspected when at its highest; the principal survey is best taken when it is at its lowest level. For an air span the river need not be sounded, but its width must be measured, and the levels of the banks and the highest level of the water should be taken, to deduce the heights of the masts and the minimum admissible height of the wire. As high masts cannot as a rule be made angle poles, the sites for their erection should be chosen so as to allow of the junction of the land and span wires being placed in a line with the span, and at a distance from the masts calculated to allow the standard dip below the terminal insulator; and a road or railway line should leave the road or rail so as to join the span without angles unnecessarily sharp or numerous. If a stream has to be crossed by a cable the levels of the banks, of floods, and of low water, the depth, nature of the bottom, current, positions of anchorages, and width, must be ascertained; the nature and extent of the changes of banks and bottom should as far as possible be ascertained by examination and inquiry. In taking levels the theodolite, water level, mirror level, or other available instrument may be employed;

the section should include the terminal poles or junctions of the span or cable with the land line. A trial line should be ranged by whites, staves, or pegs, and this line levelled if necessary; a second trial line is taken, and the process repeated, until a suitable line is found; in all cases before taking levels, lines are ranged on the ground; and if these are to be marked on the plan, then their positions relative to surrounding objects, particularly to the sites chosen for masts or other structures, must be measured for placing on the plan. The last post of the line, or the junction post, or a peg marking its site, furnishes the best datum point to which levels may be referred, and several bench marks are necessary when taking soundings. A river may be examined as follows:—The engineer is rowed across several times between different points, taking soundings to obtain a general idea of the nature of the bottom and the depth. If these be found suitable—that is, the bottom has no abrupt differences of level or rocks likely to cause injury to the cable—then a set of soundings may be taken for entry on the plan, and to mark the line in which the cable should be laid. A graduated post or staff should be erected in the water near the beach, its level should be taken, and the variations of level of the water should be observed on the staff while the soundings are being taken; at a signal from the boat the level of the water can be read off as each sounding is taken. Two poles should be ranged on shore in the line in which it is desired to take soundings, as AB, fig. 82, and a third pole C is placed at a measured distance from B; the surveyor then proceeds across the stream, keeping in the line ABE, and at the moment of sounding he takes the angle between B and C, as B1C; this angle, the angle CBE, and the length of the side BC, being known, the distance B1 may be calculated, and the position of each point sounded determined; the tide gauge being read at the same instant by the man on shore, the data required to draw a section of the stream in the direction AE may be obtained, or the depth at each point may be marked on the plan. The readiest mode of plotting the soundings is to draw a line FD through C parallel to AE, and set off at C angles equal to those measured; the points in which the lines 1C, 2C, &c., cut AE represent the points at which soundings were taken; for the angle A1C is equal to the angle DC1, &c. The position of C should be so chosen that the least angle measured may exceed 30°. Both in the preliminary survey and in marking out the line, damage to property should be as far as possible avoided;

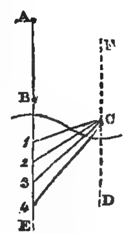


Fig. 82.

avenues of trees along public roads should not be injured; the clipping of branches may be necessary, but all beyond this should be avoided by marking the line inside or outside the avenue or under the trees. The last position should be chosen with great caution, as falling branches may damage the line during storms; this is more likely to happen with very old trees, and when the trees are much higher than surrounding objects.

434. In despatching stores, packing charges should be economised by dispensing with packing cases as far as possible; insulators, tools, and small articles are necessarily packed in boxes; line wire is made into coils, and bound with red-hot wire, which by its contraction on cooling compresses the coils together. Thin wire is packed in boxes, gutta-percha and India-rubber covered wire in air-tight drums of thin sheet iron or zinc; stays and ties may be tied in bundles; anchors, cross feet, base plates, &c., may be tied up in bundles with wire or shipped loose; cable is coiled either in water tanks or simply in the ship's hold, the layers being separated by planks or pieces of wood. Packages and bundles should not exceed a weight easily handled; 200 lbs. is a heavy package, 150 lbs. is a good maximum in practice; if much heavier the cases get broken, or the articles are liable to be roughly used, and large packages are inconvenient to distribute. Twenty-five large or fifty small insulators are sufficient in one package. The number of packages and the contents of each package should be stated on the advice of despatch; every case should be distinctly marked in at least two places with the nature of contents, or with a number corresponding to a number on the advice list. Care should be taken to avoid cartage as far as possible, and rather than cart stores to a place of safety, it is usually better to employ a watchman to guard them for the short time between their receipt at one place and re-despatch to another, stacking them on the spot. A number of stations on the route of the projected line are selected as depôts for stores, from which the materials are ultimately distributed; the ultimate distribution may be carried on with the work of construction, in this case the distribution must be kept somewhat in advance of the construction to prevent delays, but small stores should not be distributed much in advance of the construction, as they are thereby liable to be stolen or lost. Insulator cases should be opened by the men who have to erect the insulators, but not until actually required. Solder should be served out to the men, and not deposited on the line; posts may be distributed far in advance of the construction, but they should not be suffered to lie on wet ground long. For primary distribution as many depôts as possible should as a rule be

selected, as the cost of distribution is thus cheapened and is more under control; the ultimate distribution on each section should not be equally from the two depôts at its extremities, although this would be the cheapest mode; it is found more economical in practice to distribute rather more from the depôt from which the construction proceeds, as otherwise stores may be overcarried; in India not more than two-thirds are distributed forward, one-third is distributed backward; the inequality may be much less with advantage if requirements have been closely calculated. On railways, stores are distributed by special train, stopping regularly at short intervals; or are deposited at each station. When carts or animal carriage must be used along the whole line, and the stores must be distributed from each end, the small stores only should be conveyed to depôts on the line, and the poles, insulator cases, and heavy stores generally should be distributed directly from the ends of the line. It is a great advantage if the line can be marked out before the distribution is commenced; this course leaves the engineer free to superintend the execution of the work more minutely, and the distribution can be better done. The work of distribution in large towns and in countries covered by a close network of railways, roads, and canals, is a very simple matter. In laying pipes for underground wires in towns the stores must be distributed as required. In distributing generally care must be taken to place the stores out of the way of traffic on the track, road, railway, or towing path, as the case may be. Carts and bullocks in India are preferably hired, but if required for regular employment for several months, it is more economical to purchase them and sell when done with. In using canoes and lightly-built boats such as those used in India, the cargo should be well distributed, and not a full one, as such boats are unsuited to other than distributed cargo, as grain, salt, &c. In employing a large number of rough carts, consider the load admissible on each wheel and axle; do not exceed this, and if the supply of carts is deficient carry extra wheels in case of accident. Men handling stores in large quantities, as in stacking, loading waggons, &c., should be furnished with leather palms to save their hands, rope slings, and other simple appliances to facilitate their work, as labour is thereby saved, and the stores are less liable to be roughly used.

435. The work of construction is usually best performed by small independent gangs of men; if the men work in large bodies they do less in proportion to the number employed; even in clearing jungle, when a large number of men have to be employed at the same time, they should be separated into gangs, and the

men in each gang should be spread, excepting when thorny jungle (like cane) requires many men to work together.

436. For digging holes steel spades, or in India phaoras are used; for hard soil, picks; for making small holes, crowbars or jumpers; for filling in earth, sometimes shovels, but generally the steel spade; for consolidating it, rammers with long handles. A gauge, fig. 81, may be used to place posts correctly in plan, and a plumb rule may be used to place them correctly vertical. When the holes are deep, baskets may be used to hand up the earth. Boring tools are used for small deep holes. As a rule only steel spades should be carried, rather than both spades and shovels. Pole holes are usually dug by men working singly, each man digging a fixed number of holes as a day's work; if the ground be very hard, two or even three men may work at the same hole; if the ground be rocky, then cairns or plinths of masonry may be erected to receive the poles, or shallow holes may be jumped and the poles fixed with cement or plaster. In the last case cross feet or earth plates are always dispensed with, and frequently also in the second; the lowest segments of iron poles to be inserted in rock are commonly shorter and smaller in diameter than those to be inserted in ordinary earth, the upper part of the pole being the same in each case. Generally in hard soil the cross feet or base plates may be dispensed with, and unless the soil be very bad or the post be of very small diameter, it is cheaper to insert the poles a depth sufficient to admit of these being dispensed with than to use them. In forming embankments, digging large holes for masts, digging trenches for tubes, cables, &c., many men are employed together; but for boring and digging many holes of the same size the men should be employed either singly or in small gangs. The holes should be completed at least half a day's work in advance of the poles erected. If large holes be dug to receive cross feet, they cannot be dug much in advance on long straight lines unless a gauge or frame be used to place the poles exactly on the spot marked; for if the poles be put into the holes by the eye alone the alignment cannot be kept, and when many intermediate poles occur together —*i. e.*, without angle posts between them—the line will be departed from, and the holes require to be enlarged or others must be dug; hence the superiority of holes narrow at right angles to the alignment—they may be dug far in advance, and consequently admit of the work being carried on quickly without fear of alteration being necessary, and labour is saved; but some of the objections to large holes are removed by the use of the gauge. When the ground is so hard that it is cheaper to erect cairns or plinths of rough masonry than to dig holes, then the former

should be preferred. Plinths are built of rough coursed masonry, the blocks being merely quarry-faced; cairns are simply heaps of stones with wet earth or clay instead of mortar. In India they are built in four courses; they are 6 feet diameter at base, 3 feet at top, conical in shape, and 3 feet high; the pole is inserted 8 inches in the solid ground below, and the whole is covered with earth and sown with grass. Whenever suitable stones can be procured cairns should be built as described for rubble masonry; when cairns or masonry plinths are employed, the pole should always be placed a short distance in the solid ground, and temporary stays of cheap rope should be applied until the work has set.

437. After the holes have been dug a gang of men erects the poles. The number of men it is most economical to employ in this gang depends on the weight of the poles, the size of the holes, the strength of the men, the capacity of the man directing each gang, and the mode of erecting the poles, as in some cases shears or a gyn is used. The number of men in one gang ordinarily employed to erect poles in India is ten or twelve; this number is sometimes increased to twenty or even more. The erection of short poles on houses admits of the employment of only two or three men at each pole, and the work often requires considerable mechanical skill. The insertion of brackets in walls can employ profitably only the skilled mechanic and one or two labourers; the erection of masonry or brick plinths employs only the mason or bricklayer, and a sufficient number of labourers and stone-cutters to lift and cut the stone and bring and prepare the materials. In India ordinary lines of poles outside towns are seldom erected by gangs smaller than twelve men each, and these are divided as far as possible into smaller parties by the inspector directing them; some of the men go in advance and lift the poles into the holes; if the holes are small, so that the pole can be placed at once correctly in the alignment, two men are sufficient to fill in and ram the holes; if the hole be large, the pole is put correctly in the alignment by a second party directed by the foreman directing the gang; when correctly placed, the hole is about half filled in and left to be completely filled and rammed by small parties of two men each which follow. In dividing the men they should not be so spread as to be beyond supervision. If a gauge be used, the second stage of the process is greatly facilitated; it is performed by measuring, instead of by placing the pole in the alignment by the eye alone. When only three or four intermediate poles occur between two angle posts they may be placed correctly by the eye, but on long straight lines, if large holes be dug the gauge should be used; with narrow holes or bored holes, but slightly larger than just

sufficient to receive the pole, the skilled labour of the foreman is dispensed with, and the hole may be filled in and rammed at once. It will be seen that although the gang employed erecting poles may be large it is subdivided, and the men work in small parties, the largest party being just sufficiently numerous to handle a pole easily. If the holes be small the earth may be consolidated by shaking the pole, and by using a crowbar to ram it. Stones or old bricks may be used to render the poles firm in bad soil, or under other circumstances rendering such necessary. Cross feet of wood, or pieces of timber properly disposed, are used sometimes with wooden poles in bad soil; they may be bolted to the pole or merely buried in such a manner as to distribute the pressure over a greater area of soil. Poles should only be put approximately vertical until the hole has been half or three quarters filled; the plumb rule may then be applied, and the post placed truly vertical. Anchor holes do not differ from post holes, excepting that they are sometimes somewhat deeper, and they have a narrow trench cut on the side towards the pole to admit of the tie passing in a direct line from the clip to the anchor. Sometimes the holes are undercut on the side next to the pole. In India these holes are dug 4 feet long and 2 feet deep; they are then dug an additional 18 inches deep at the end near the pole, so that the anchor is 3 feet 6 inches deep. In rock a stout rod with an eye at one end may be leaded into a hole cut or jumped in the rock in a direction inclined from the pole; the ring projects and receives the tie. This arrangement is applied to masonry and brickwork; timber may be employed instead of an iron bolt, or cast iron may be used. Stones are often used for filling anchor holes when at hand. The gang erecting poles also erect stays and ties. Some poles, as Siemens', are erected by means of light shear legs; such aids are useful when many tall posts have to be erected in succession, but are not generally economical for ordinary poles up to 18 or 20 feet. For lifting the cast-iron lower segments of large posts a derrick may be used, and this or a pair of light shear legs may be used to lift tubes for underground lines into position. When the brackets or tie clamps are merely bolted round the pole, as with most iron poles, the best mode of procedure is to bolt the brackets loosely to the pole, leaving the work of placing them correctly across the alignment to be done after the erection of the pole; but if the brackets have to be let into the pole, or bolted, as with wooden posts, they may be fitted to the poles by mechanics at the depôts previous to distribution. The brackets, when short, are usually placed across the alignment by the eye alone; this is exceedingly easy at angle poles, as the direction of the anchor marks the

proper direction for the bracket, but at intermediate posts the proper direction may be found by one of the methods used for offsets. A very convenient mode is to have an endless string with three pins attached at intervals, such that when pegged down with the string tight it forms a right-angled triangle; by placing one of the sides containing the right angle in the alignment, the other marks a line at right angles to it. Lightning spikes, insulators, and other fittings, if distributed with the poles, should be erected with them, as a general rule, being fitted on the ground before raising the posts; but these should not be taken from the packing cases until actually required. The earth filled in round poles placed in large holes should be rammed in thin layers, the surplus soil being placed round the pole to allow for sinking. On inclined ground the earth should not be heaped high *above* the place of insertion of the pole, but it should be heaped and well rammed below the pole, as poles on inclines have a tendency to lean over towards the normal to the inclined surface. To prevent the earth round the pole being washed away instead of sinking, it may be covered with sods. When poles are erected on embankments the turfing of the bank round the poles should be replaced to avoid injury to the bank. Poles placed on the edges of roads should have short posts erected to protect them from being struck by wheels of passing vehicles, and the tie rods should be similarly protected where they enter the ground. Great attention should be given to the foundations of masonry or brickwork pillars or plinths; pillars should taper upwards, and have well-spread footings. Tall poles are used on each side of railway crossings; the wire is stopped on each side of the crossing, but it should not be stopped on the tall pole; hence a terminal pole is necessary on each side of the crossing.

438. Wire is payed out, if thin, from a drum or reel of wood or galvanised iron; one cheek or disc of the reel being removable, is removed, the coil of wire is placed on the core, and the cheek bolted on again; the reel is mounted on an axle, fixed either in a light frame which can be carried in the hand or hung by hooks on any conveniently shaped object. The reel is frequently mounted on a light handbarrow or stretcher; a convenient form for the reel when so mounted is that of a frustrum of a cone, the axis is in this case placed vertical. For thin wires and for the stranded wires used for town lines and river crossings the reel is indispensable; for thick wire similar reels of suitable size are used, they are either carried by the axle by two men or rolled along the ground by one man, the latter mode is probably the most convenient and economical. For thick wire the reel may be dispensed with and the coil of wire opened by rolling it along

the ground, but this is troublesome, and the use of a reel should be preferred. All wire should be laid out by causing the coil to revolve, it should *never be pulled from the coil in a spiral* and straightened. As one set of men unroll the coil, a second set follows and makes the joints. Thin stranded wire and No. 8 and smaller wire may be joined by the twisted joint; in joining stranded wire in this manner the strands may with advantage be separated at the ends to be twisted round the main wire so as to form a closer joint, and generally in twisting stranded wires together to form joints or eyes this should be done. One or two men per wire are sufficient to unroll; if the wire be thin two men can unroll it and make the joints, if thick two men are necessary to make the joints and carry the fire, fuel, and tools, but these men can joint several wires, as while one man solders one joint the other can be twisting or binding another. The source of heat employed for construction is usually a small plate iron stove or furnace convenient to carry, the fuel is wood, coke, charcoal, or other procurable, preference being given to that which is light and gives a hot clean fire. Two irons should be used, and each iron should be just large enough to make one joint easily with one heat. For repairs and occasional use the best source of heat, particularly in towns, is a lamp furnace, a self-acting blowpipe, or a joint furnace of sheet copper burning prepared fuel. When the wire has been joined it may be strained, the men employed straining should follow those jointing at a distance within half a mile. The straining party fixes a tackle to the wire by claws or a stopper, the other end of the tackle being fixed by a loop of wire to the base of a pole the line wire is hauled tight. Before straining, the wire is placed on the angle insulators, and it is strained usually about a quarter of a mile at a time. The wire on straight sections is strained on the ground; some workmen strain it on the insulators, others on the brackets of intermediate poles, but it appears better to strain on the ground for long straight lines, and on the angle insulators only when angles occur; but in some cases, as on town lines and on high masts, the wire must be strained on the insulators. It is placed on the insulators at angles, long spans, and on high masts before straining, as it could not be raised afterwards without great difficulty. It is better to strain on intermediate brackets than on the insulators, because joints in the wire are less likely to catch. It is better in most cases to let wire hang between the angle poles, suspending it on the angle poles only while straining, because it affords a means of measuring the tension; it is exceedingly difficult to judge by the eye when the dip is small, as in a standard span of 100 yards, but if while straining the wire be suspended from two angle poles

300 yards apart, the dip being assumed to be as the square of the span, it will be nine times the standard dip; its amount and consequently the strain on the wire may be readily judged by the eye by regarding the distance of the wire above the ground, the height of the poles and standard dip being known. After the wire has been strained it is lifted and placed on the intermediate insulators. After the wire is joined it is sometimes *killed* by being loaded suddenly, the object of this is to take the spring out of it; at other times the wire is loaded to its proof tension, kept so for a few minutes, and then slacked to the working tension. If the wire is new, soft, and properly payed out, killing is not necessary; there is manifest advantage in exceeding the working tension for a short time when straining the wire, as it tests the wire and joints, but it is not necessary to strain to the proof strain nor to keep the wire long strained. If the wire be hard, or if it be old wire and consequently bent, it is necessary to either kill it or strain it to almost its proof strain; for if this be not done much inconvenience may be caused by the dip increasing considerably after the line has been completed. Lines over populous towns cannot always be strained to their proof strain for fear of accident to passengers; with stranded wire this can be dispensed with, as the wire is more flexible. When a river has to be crossed, if there be little or no current, the wire may be placed on one of the masts, then payed out from a boat to the opposite mast, landed and payed out very slack to the terminal, it should then be placed on the second mast, and tightened by tackle attached to the base of the terminal pole. If the wire does not rise readily from the water, a boat must be passed under it to lift it from the mud or weeds. If there be a strong current in the river the wire may be crossed before placing it on the mast; it should be payed loosely from the boat, and more than one boat should be employed; when the end of the wire has been landed, one or more boats may be passed backwards and forwards under the wire after it has been placed on one or both masts to lift it from the bed of the river. Another mode is to anchor several boats in the stream, and lay the wire on the boats instead of letting it sink in one length. The most satisfactory mode of regulating the tension on the wire is the use of a dynamometer, and this should be used invariably on long spans where the minimum dip is allowed. In Prussia the tension on long spans is maintained constant by the following contrivance: The end of the span wire is wedged in a clip, the clip is attached to a short chain the other end of which has a weight attached, the chain is passed over a pulley attached by a short movable arm to the insulator on the mast, the span wire is thus kept

tight by the suspended weight. The objections to the above arrangement are the manifest inconvenience of suspended weights, particularly when the wires are numerous, and the fact that the load on the top of the mast is unnecessarily increased; a spring inserted in the wire would have the same advantages without the disadvantages. The number of men employed straining wire depends on the number and weight of the wires; two sets of tackle should be allowed to each gang, that one tackle may be in process of adjustment while the other is in use, and the second may be strained before the first is slacked for removal. When there are more than two wires a separate gang of men should be allowed for each pair when two wires only are on the same level, or for each pair of brackets or cross arm, when more than two wires are on the same level, until a straining gang is employed straining at each post; thus if the wire is strained at every third or fourth pole, three or four gangs may be straining independently. If the number of wires on the cross arms differ, then one gang may strain the wires on one cross arm, while another gang strain an equal number of wires on two or three cross arms, care being taken to so divide the work that the gangs progress equally, that they progress at about the same rate as the erection of the poles, and yet no time or labour be wasted by unnecessary transfers of tackle. When two or more wires have to be strained they are best strained in pairs; this saves time and labour, and ensures equality of strain on each wire of the pair. The best mode of straining two wires at once is to use a short rope passed through a single block, each end of the rope is fastened by the usual means to one of the wires to be strained, and they are then strained together by the tackle being applied to the block; the wires being balanced through the block, they are equally strained. A snatch block is more convenient than an ordinary close block to reeve the rope through and strain on. The above refers to construction of a line without winding drums or stretching insulators; when winding poles are employed the two ends of wire at each winding pole are drawn towards each other by tackle, placed on the drum, and the tension carefully adjusted; practice enables the workman to judge of the tension by the force necessary to turn the winding key or lever, but this mode is not so accurate as using a dynamometer or measuring the dip on an increased span. The use of winding drums on high masts should not as a rule be permitted; the wire should in such cases be strained from below, and never by using the mast as a fixed point to haul against. By adhering to this rule less expensive masts may be used than if the wire be strained against the top

of the mast, and there is no advantage in departing from this rule. At terminal poles the wire is fixed by a stretching insulator, or formed into a ring to fit the head of the insulator; it may be strained by a movable ratchet drum and winch attached to the terminal pole; the chain of the winch being attached to the wire, the winch is turned until the wire assumes the required dip, the wire is measured, slacked, the terminal ring made, the wire drawn again tight by means of the winch, the ring is passed over the head of the insulator, and finally the winch is disconnected. Over-house lines in towns are as a rule strained at terminals by means of the winch, but outside towns terminal poles occur but seldom, hence for such lines it is better to use the ordinary tackle than carry an extra heavy tool, the use of which offers no advantage when there is room to use the tackle, as described below. To terminate a line with the ordinary tackle proceed as follows:—Let the line lie on the ground for about 500 yards, measured from the terminal pole, draw the wire tight by hand, turn a ring on its end, place the ring on the terminal insulator, then fix the tackle on the line 200 or 300 yards from the terminal, draw up a bight of wire, and make a joint so as to shorten the line to give the normal dip. When laying the wire out at a short distance from the terminal a temporary joint should be made, the wires being merely twisted together; after the ring has been placed on the terminal insulator, the bight is taken up by fixing the tackle across this joint, which is then cut out and the wire permanently joined in the usual manner; thus there is no waste of labour, and no more joints in the wire than the number of coils of wire renders necessary. Winding drums, shackles, eyes of porcelain, &c., are usually very inferior in insulating power to ordinary bell insulators, hence their use should be avoided whenever possible, particularly on long lines; when they are really necessary, additional shelter from rain may be afforded by applying light pent roofs of wood or metal to keep the supports dry. The best mode of terminating wires at offices, junctions with cables, &c., is by means of the ordinary bell insulator fixed under shelter, the conductor being continued into the office or junction house by a piece of well taped and tarred gutta-percha or caoutchouc covered wire; the joint should be soldered, and the covered wire changed when the covering has cracked from exposure. Some administrations use a small insulator for leading in wires rather than the large insulators in general use—this is the case in Prussia; the small insulator is the more convenient and economical for leading in wires at offices. At long spans, as river crossings, the span and line wires may be terminated on the same insulator,

but the contact should be made perfect by a piece of thin wire soldered between them. Before straining the wire all stays and ties should be tightened. On light temporary lines the insulators and brackets being in one piece, are spiked to living trees or lashed to wooden poles usually by a serving of wire; the line wire is not usually thicker than No. 12, and it may be sufficiently strained by hand without tackle, a mile weighs but little more than one and a half cwt., the joints are not always soldered, but solder should be employed whenever practicable, the attachment to the insulators is usually by thin wire placed in a groove round the insulator. The wire is usually lifted and placed on the insulators by means of a light fork, or it may be lifted by a man on a ladder; the ladder is more generally useful but heavier to carry than the fork, the best plan is to use both, using only one ladder and several forks. A natural fork of bamboo is the best fork used in India, but if wooden forks be not readily procurable an iron tip may be fixed on a wooden handle. One man is sufficient to carry a wire up a mast, but the wire must be very loose; the best plan on a high mast is to send up the large block of the tackle with the rope reeved once through it, this is hung by its hook to the bracket at the top of the mast, the wire being placed on the hook of the small block, it is raised to the top of the mast by hauling on the fall, a man then lifts the wire from the hook and places it on the insulator. As the wire is strained against the poles the latter are often drawn out of the vertical, they should be put upright after the wire has been placed on them. If stretching insulators be used the wire should of course be fixed as it is strained; if the wire is to be bound at each insulator, this is done by men following the straining gangs; but these men should be kept two or three miles behind the straining gang, as if the wire be not permitted to adjust itself before being tied it may do so afterwards, and the posts will be drawn out of the vertical. In laying underground lines the tubes are first cleaned and smoothed, the iron tubes with a heavy iron chain, the stoneware tubes with a scraper, formed of two irons shaped like half tubes, kept apart by a spring and fitted to a handle. The iron tubes are joined by first ramming in a little yarn to prevent the lead running into the pipe, making a clay mould round the pipe, pouring in the molten lead, and ultimately removing the clay. As each pipe is laid an iron wire not smaller than No. 16 B.W.G. is placed in the pipe, the wire being continuous from draw box to draw box. The wire may be in the form of cable or single wires properly insulated and covered with tape; in London the wire is commonly No. 18, covered with gutta-percha, to No. 7, and served

with tape soaked in Stockholm tar; the wires are in lengths of 400 yards, they are tied together at intervals, and as the bundle is drawn into the tubes the strings they are tied together with are removed. When the number of wires to be drawn in is large a larger sized iron wire may be drawn in by means of the wire laid with the pipes, and the larger sized wire used to draw in the insulated wires. The insulated wires are attached to the iron wire by a ring made on the end of the latter, the insulating material is removed for a short distance from each copper wire, and the copper wires are placed through the ring on the iron wire and twisted; to protect the ends of the insulated wires while being drawn in they are wrapped in tarred tape, yarn, or other similar suitable material. The best material for the tapes is cotton, and they should be woven straight with a double selvage, so that they be not stretched out of shape by the covering machine or in jointing. If a wire be broken in drawing in, the position of the break is ascertained by withdrawing it entirely and measuring the pieces. If the break be in an iron pipe the pipe may be broken, if in a stoneware pipe the section of pipe is uncovered and opened at the joints. Wires cannot be readily threaded through the pipe for long distances, even when the wire is comparatively thick, as No. 8, and the pipe empty; hence, if the distance between the break and the nearest draw box is too great to admit of a wire being threaded through from one end of the section, a hooked wire must be inserted at each end—viz., the draw box and the break, and these wires be moved round until the hooks catch, when the required communication being established the repaired wire can be drawn into the tube. If of stoneware the tube can be re-laid in the usual way, if of iron the broken part of the tube is encased in a short section of tubing supplied for the purpose, of a size to fit outside the broken tube, and made in two pieces to be fitted together by bolts passed through longitudinal flanges, so as to tightly encase the broken tube at and for a short distance on each side of the break; the joints at the ends of the short tube are packed to close them effectually. The boxes containing the joints of the several lengths of insulated wire are termed *joint boxes*, they are necessarily placed every 400 yards, as the core is made in this length; they have cast-iron removable covers laid flush with the surface of the pavement, and are open to inspection. The intermediate boxes, termed *draw boxes* or *flush boxes*, are of the same or similar pattern; but as they need not be open to inspection, being required merely for the purpose of drawing in and out the wires, they are commonly covered up; the situations of each of these or of some of them may be marked in any con-

venient manner, as by letters cut on the paving. Draw boxes are required at angles, and must in many cases be distributed irregularly; the maximum distance admissible is probably 200 yards, a convenient distance is 100 yards, the former should not be exceeded, less than the latter is not necessary, unless a shorter distance be imposed by the nature of the route. The insulated wire should be protected by a roller or other appliance from injury by friction against the edges of the pipes, and the drawing in should be performed on each end of each section of the wires, being commenced from the centre draw box of the section to be drawn in. The insulated wire or cable being inserted at one draw box, drawn out at another, re-inserted, &c., several times in each section of 400 yards, if it be coiled each time it is drawn out, for each coil one twist will be put into it when it is re-inserted, unless this be provided against. The wires must either be received on a drum, laid on the ground, or coiled on one side of the draw box as drawn out and turned over by recoiling on the opposite side before being re-inserted; the last is the most convenient mode, and is that generally followed. The wires should be coiled on canvas, and not on the bare ground, to prevent the introduction of grit into the pipes. The above refers to the laying of wires when numerous, modes of laying less numerous wires are described in Section I.

439. The tools should be very strong and of as few patterns and sizes as the proper execution of the work will permit; for special work of course special tools may be really necessary, but the general utility of the tools for repairs and maintenance should be considered. The construction of a line is carried on as rapidly as possible, to save cost of superintendence, by employing as much labour at the same time as can be efficiently supervised; the principal difficulties are to mark the line rapidly enough, and find a sufficient number of intelligent men to act as foremen; the rapidity with which the work can proceed is usually limited by one or both of these conditions. It is an excellent plan if a preliminary survey has to be made to mark the route of the line, and if the route has been definitely decided on to set out the work. Sometimes the poles are erected first, and the wire is erected as the working parties return, but the most economical plan is to complete the line at once, the work being set out if practicable in advance. If there be dearth of carriage to distributed stores, the poles, wire, and insulators should be distributed before commencing construction, to remove the possibility of delays after labour has been engaged.

Section IV.—*Submarine and River Cables.*

440. The essential parts of a cable are, the conductor, the insulator, and as the conductor and insulator are deficient in tensile strength, this deficiency has to be supplied by the addition of a tenacious material, commonly iron wire, usually applied in the form of a covering. Other matters, such as Chatterton's compound, artificial asphalt, and hemp, are used to make the cable solid, to prevent air spaces, to protect the iron wire from oxidation, &c.; applied for these purposes, these materials may be termed accidentals.

441. The conductor is almost invariably of copper, the object being to obtain the maximum conductivity with the minimum sectional area. As the conductivity of copper varies considerably according to the degree of purity of the specimen, the copper employed should be carefully tested, and a conductivity 90 per cent. of that of pure copper may be insisted on. Blavier fixes the minimum at 75 per cent., but the care which has been bestowed on the subject has recently led to great improvement in this respect. The specific conductivity of some cable conductors actually laid has exceeded 95 per cent., of but few recent cables is it less than 93 per cent. Iron wire may be used as the conductor in short cables for crossing rivers or for underground, but it is seldom if ever employed. Its advantages are extra strength and low price; its disadvantages are greater weight and bulk for equal electrical resistance as compared with copper—consequently, for a given conductivity and insulation more of the insulator is required. Preference is given to stranded rather than single wire for conductors; either three wires twisted together, or generally six wires twisted round a seventh, are used. The advantage of employing stranded wire is greater flexibility, and consequently increased security against rupture by repeated bending, and these advantages far more than counterbalance the disadvantages of greater quantity of insulator being necessary to cover a conductor of given electrical capacity. Short lengths of cable for rivers may have single wire conductors where it is desired to reduce cost. Messrs. Clark & Bright have introduced a strand of wires of such section that they fit together to form a cylindrical conductor, but some manufacturers have experienced difficulty in carrying out the suggestion. In the direct United States' cable, made by Messrs. Siemens, the conductor consists of one central thick wire and eleven thin wires, flexibility being in a measure sacrificed to gain increased conductivity. The several wires should break joint and should be

joined by silver solder, rosin being used as a flux. The object of using silver is to avoid gnawing of the copper, and rosin is used to prevent the corrosion which might occur if chloride of zinc were used; a corrosive flux, if not entirely removed after soldering, might seriously endanger continuity of the conductor after the cable had been laid. The diameter of the copper in long cables varies from about ·087 to ·170 inch, and the weight of copper per knot from about 90 to 400 lbs.—the heaviest conductors being used for the longest cables. Great care should be taken to select soft tough copper, and to so arrange the wires that the diameter of the conductor and its conductivity shall each be as nearly as practicable the same throughout. In laying the wires together, as it is highly desirable to make the cable as solid as possible and produce adhesion between the conductor and insulator, in gutta-percha core the wires are laid together with a mixture of silicated bitumen, artificial asphalt, Chatterton's compound, or other similar material, in just sufficient quantity to fill the interstices between the strands; in Hooper's core the centre wire is covered with separator.

442. In gutta-percha core the layers of gutta-percha are cemented together by Chatterton's compound. When there is adhesion between the covering and the conductor, these stretch and shrink together, and the conductor cannot, while continuous, be forced through the insulator, an accident which used to occur before this measure was introduced. The insulator is put on as described in Part II., chap. iii., sections 1 and 2. The size of the conductor and thickness of the insulator are determined by electrical considerations (see next Paragraph). Cable core is comparatively very weak, and but little of its strength is available by reason of its extensibility—*e. g.*, the core of the Anglo-American cable made of 300 lbs. of copper and 400 lbs. of gutta-percha per knot, stretches 10 per cent. with a quarter of a ton; this does not impair its electrical efficiency, but the elongation of a completed ordinary iron-covered cable is under 1 per cent. when loaded with half its ultimate load. It is evident the strength of a cable is practically that of the guards. Over the insulator a serving of hemp is put on to form a padding for the outer guards to rest on. This hemp is spun on by a machine consisting of a circular revolving frame carrying drums of yarn, through the axis of the frame the core to be covered is drawn by being passed several times round a drum or wheel connected with the frame, carrying the yarn in such a manner that their rates of revolution bear the necessary relation to each other. The hemp serving may be saturated with bituminous or tarry matter as a preservative; but, as a rule, it is tanned

or brine is used, the objection to using the other materials being the possibility that faults in the insulator may be temporarily hidden thereby. Sometimes several cores are laid together, hempen strands are used to fill the spaces between the cores, and the whole is then served with hemp, as described for a single core. Multiple conductor cables are not used for long distances. The outer covering of the cable is varied with the depth to which the cable has to be laid, and its liability to disturbance and injury by friction against rocks, &c. The materials employed are good iron, homogeneous metal, or homogeneous metal together with hemp. The weight of iron may vary from little more than half a ton per knot to upwards of 17 tons, and that of the completed cable from 1½ ton to 20½ tons per mile. The guards are spun on by a similar machine to that used to serve the core, the wires being wound on large bobbins fixed in a revolving frame, through the axis of which the core to be covered passes; they are laid on without being individually twisted, and as nearly as possible with equal tension. In one of the best forms of covering machine the bobbins carrying the wires are attached to an iron disc, through the centre of which the cable core passes, each bobbin is attached to the disc by a spindle, so that the bobbin is always suspended vertically on the face of the disc, thus the bobbins move round the core without twisting the individual wires round their own axes. The number and size of the wires are adjusted to the size of the core to be covered, that they may exactly cover it and abut against each other when the cable is strained, in order to prevent the cable stretching and the core being compressed by contraction of the helices of the covering. To place the wires close, the cable as it leaves the closing machine passes through a hole or between grooved rollers, which press the wires together. In calculating the length of wire in the outer covering 3 per cent. is commonly allowed for lay, the turns being very long to avoid injury to the wire by the twisting, and to keep the abutting wires as parallel to the longitudinal axis of the cable as consistent with forming a rope which may be conveniently handled and has no tendency to kink or for the strands to rise. Carefully made, the completed cable should be hard and solid, not spongy; it should not have the spring and liability to kink seen in single wires, should coil readily, and not stretch with half the breaking weight more than one-half to one per cent. When strained in great length cables untwist slightly, and consequently elongate from this cause, but such elongation is too slight to be of consequence. The wire guards are galvanised, and the cable is covered with a serving of coarse hemp or jute, and a mixture of bituminous matter and silica

(frequently termed asphalt); the outer serving protects the wires from rust, it holds the wires down, furnishes additional security against strands rising during paying out, and incidentally it eases the cable in paying out by causing increased friction between the cable and the water, and by lowering the specific gravity of the whole. The smallest number of wires used to cover a cable is 9, and 18 is seldom exceeded; the former form a rope inconveniently stiff, 12 make a suitable rope. For shore ends, and generally for cables liable to attrition, to be caught by ships' anchors, &c., thick wires are used, the iron in the heaviest cables weighing as much as 17¾ tons per knot; the wires are not, however, put on singly, such a cable would be too stiff to handle, but the cable is covered with 10 or 12 strands, each of three wires. The part of the cable for considerable depths not being liable to injury from causes mentioned above, is usually light, only sufficient strength being given to admit of the laying and, in case of necessity, raising of the cable; thus, in the French Atlantic cable the main cable has only ·709 ton of iron per mile, in the English Atlantic cables it is still less, while in shallower seas it may reach 8 tons per knot; 2 tons may, however, be considered heavy for a main cable of considerable length. If long cables were made of large diameter they would occupy much more space on board ship, and more joints would often be necessary—hence the longest cables are made of as small diameter as practicable. There would manifestly be considerable difficulty in joining a heavy shore end directly to a slight cable, and the heaviest cable is not required to meet the lightest main—hence, between the shore end and the main cable one or two intermediate sized sections, termed intermediate cable, are interposed. The core is uniform for main, shore end, and intermediate cable, the only difference being in the weight of the guards. The different sized sections—*i.e.*, the main, intermediate, and shore end, are joined to each other in one of two ways, either by a taper, or by serving the thinner cable (guards included) with hemp, and laying over this the guards required to form the shore end. When joined by a taper the larger guards gradually take the place of the smaller, thus the sections are formed by a taper; but when the other arrangement is employed the guards of the smaller section are continuous through the larger section, the larger differing from the smaller only in the addition of a layer of packing and an outer set of heavy guards. For deep sea cables a combination of homogeneous iron with hempen strands is used for the guards; the elastic flexibility of untwisted hempen fibre being inferior to that of the metal, the twist in the hemp is so adjusted that the two materials stretch and ultimately break

together, thus rendering the whole strength of both available. The chief mechanical advantage in the combination of hemp and wire lies in the fact that the hemp so used adds its strength to that of the wire, while it does not add sensibly to the weight of the cable in water; in other words, it increases the strength of the cable by an amount equal to its own tenacity, without adding to the load to be borne; hence it increases the modulus of tenacity in water. Good iron is used when admissible, for greater depths homogeneous metal is used, and for the deepest seas the combination of homogeneous metal and hemp. Shore end cable is used for river crossings as a rule, but the heaviest is only employed exceptionally for this purpose; it is used with marine cables up to depths varying from two to three hundred fathoms. The combination of hemp and homogeneous metal is not used for depths less than 1000 fathoms; an iron-covered cable cannot be safely laid in water deeper than 1500 fathoms, for greater depths homogeneous metal is used; homogeneous metal and hemp together are used for the greatest depths. A cable with hempen guards has been projected for crossing the Atlantic, but hitherto hemp alone has not been successfully applied to the purpose. At first it was feared if the wires were put on spirally they would allow the cable to stretch when strained, and thus fail to protect the core from injury; many cables were therefore covered with iron wires laid together without any twist, and kept together by servings of thin wire at short intervals; but it is found in practice this form of cable is more difficult to manufacture, and less convenient to handle, than the spiral form, while the latter is found to answer in practice, the wires abutting against each other when the cable is strained.

443. Although not strictly within the scope of this work, it seems desirable to state the conditions regulating the absolute and relative sizes of the constituents of cable cores; these are as follows:—The dimensions of the core are determined by the number of words per minute required to be transmitted, and by the total length of the cable. The number of words which a core will transmit in a given time, if the ratio between the weights of the conductor and insulator be maintained constant, is directly as the weight of the core, it varies with the nature of the insulator, and is inversely as the square of the cable's length. The ratio between the weights of the insulator and conductor per mile is varied with the specific inductive capacity of the insulating material employed, and as a rule the insulator is used in excess of the weight indicated by theory as necessary to give the maximum speed with a given diameter of core. In gutta-percha cores the ratio of copper to gutta-percha, by weight, varies

from two-thirds to equality; the lightest core of practical use has 73 lbs. copper and 119 lbs. gutta-percha per knot, a common size is 107 lbs. copper and 140 to 166 lbs. gutta-percha; the largest core yet laid, that of the French Atlantic cable, is 400 lbs. copper and 400 lbs. gutta-percha. The diameter of the conductor in the last is ·168 inch and of the core ·470, or the ratio of the diameters is nearly 1 : 3. Blavier has shewn that the ratio 5 : 8, and another author (Sabine) 3 : 5, would give the maximum speed with a given sized core, but there is manifestly considerable risk in reducing the absolute thickness of the insulator. The specific inductive capacity of India-rubber being much lower than that of gutta-percha, a thinner covering of this material is required to obtain a given speed through a fixed conductor, and accordingly in India-rubber core the copper bears a larger proportion by weight and bulk to the insulator. As a certain absolute thickness of insulator is necessary mechanically, in a small core of Hooper's India-rubber 90 lbs. of copper and 130 lbs. of insulator per knot is used, the diameters of copper and core being ·080 and ·241 inch respectively, or as 1 : 3; medium sized core has equal weight of copper and insulator—viz., 180 lbs. of each per knot; in larger sizes the copper is in excess, thus the North China cable core has 300 lbs. copper to 200 lbs. insulator per knot, the diameters of copper and core being ·147 and ·318 inch respectively. Hooper's material is about 2·25 per cent. heavier specifically than gutta-percha. The number of words per minute n, a given gutta-percha core L knots in length, the conductor weighing w lbs. per knot, will transmit with a mirror instrument, is represented by the formula $n = C\frac{w}{L^2}$; C is a coefficient varying with the ratio between the gutta-percha and copper. The values of C for several ratios is given below on the authority of Professor F. Jenkin, the weight of copper being 100:—

Weight of Gutta-percha.	Value of C.
80	163,000
90	175,000
100	187,000
110	196,000
120	205,000
130	21,500
140	22,400
150	23,300
160	24,000

If the Morse instrument be used, n to be divided by 14; if

Willoughby Smith's or Hooper's material be used, n to be multiplied by 1·17.

444. The iron wire used being of a relatively large size, has a breaking strain of about 35 tons per square inch of section. Mr. F. Jenkin states as an ultimate load for good iron 2 tons per pound of iron per fathom—this he states is equal to about 41 tons per square inch, but calculating the intensity of this load from the table of sizes of wire given by Mr. Johnson, it appears only equal to 39·85 tons. This is, however, too high, and a more simple and accurate rule is the following:—The *working load* of an iron wire cable is one pound for each pound of iron per knot; the factor of safety being 4, the ultimate tenacity is about 36 tons per square inch. The homogeneous wire has a tenacity of 50 to 60 tons per square inch. The factor of safety usually employed for cables is 4. The maximum tension during submersion is the weight in water of a length of cable equal to the maximum depth of the sea in which it is to be laid, less the friction between the cable and the water. If the cable has to be raised from the end or on the bight, the cable forms a catenary, the resistance of the water which, as stated above, diminishes the stress during immersion, increases the stress when the cable is being raised; this resistance being as the square of the velocity there is manifestly advantage in raising a cable slowly when the tension is considerable. The tensile strength of the cable is practically that of the guards only, the core being comparatively weak and but little of its strength being available by reason of its greater extensibility. As the maximum strain is only borne for a short time by each section of the cable in succession as it passes over the stern of the ship, a maximum load equal to one-third of the ultimate load may be permitted during submersion without danger, but it is evident if accident rendered it necessary to take such a cable up there would be no chance of success. If the contingency of having to raise the cable has to be provided for, this can only be adequately done by calculating the maximum load on the cable in raising it from the greatest depth, and using at least 4 as a factor of safety. Where experience leads to the conclusion that it will probably be necessary to raise the cable, or when a cable has to be laid for a temporary purpose, then 6 should be used as a factor of safety; but in these cases the depth is not usually great, the contingency of having to raise it is therefore amply provided for without special provision. The additional weight of iron put into shore ends of cables does not increase the modulus of the cable, but the thick wires expose less surface to oxidation in proportion to their weight, and the heavier cable has greater absolute strength,

fitting it to resist mechanical violence. Shallow water cables have a tenacity far greater than is required to admit of submersion and picking up. Deep-sea cables covered with homogeneous iron wire guards have usually about 2 tons of iron per knot—this is found to answer well in practice. The Atlantic cables furnish examples of the employment of hemp and homogeneous iron together; the 1866 Atlantic cable has seven No. 18 B.W.G. copper wires for conductor, its guards are ten No. 13 B.W.G. homogeneous iron wires, each served with five yarns of Manilla put on spirally; the diameter of the cable is 1·127 inch, its tenacity 8 tons, its weight per knot 1·8 ton; in the French Atlantic, a more recent cable, the core weighs 800 lbs. per knot, the serving 234 lbs., the served core is ·669 inch in diameter, the guards are ten homogeneous iron wires each ·1 inch in diameter, and covered with five Manilla strands, each served wire is ·245 inch in diameter, and its ultimate load is 1550 lbs. The diameter of the cable is 1·134 inch, it weighs 1·652 ton per knot in air, 0·753 ton in water, its ultimate tenacity is 7·375 tons, its tenacity in air is equal to the weight of 4·4 knots, and in water to 9·8 knots of itself.

445. The completed cable is coiled in tanks, each of which has in its centre a frame termed an *eye*, having a minimum diameter of 6 or 8 feet; the cable is coiled in layers by men stationed inside the tank, each coil commences at the periphery of the tank and finishes at the eye, the cable is then taken radially to the periphery and another coil commenced; the layers are separated by sticks or planks placed radially. If the cable be covered with bituminous matter, it may be dusted with lime or other fine powder to prevent the coils sticking together, but some degree of adhesion is advantageous on shipboard, as it prevents in a measure the cable flying about when being payed out. On board ship the tanks are similar to those on the works; ships built for cable laying have the tanks arranged with great economy of space and weight. A conical-shaped frame, formed of concentrically arranged rings, is suspended over the tank; this frame being lowered into the tank as the latter is emptied, the cable is forced to pass between the iron rings and the frame or mould forming the eye of the tank, and is thus prevented from flying about under the influence of centrifugal force while being payed out. If a cable of ordinary construction were simply put over the stern of the ship, it would hang with the weight in water of a length of itself equal to the depth of the sea; no machinery is necessary therefore to get the cable to run out, when it has been payed out for a short length it will run out itself; hence it is necessary to have brakes to

control the rate at which it shall run out, by offering the resistance of friction in opposition to the weight of the cable hanging over the stern of the vessel. But it is also necessary that the tension on the cable at any moment should be known in order to use the brake; this tension is measured by a dynamometer. The essential parts of the paying out apparatus are thus the brake and the dynamometer. As the cable leaves the tank it passes several times round a grooved drum, the weight dragging the cable out causes this drum to revolve. The brake is that known as Appold's, the principle of which is described in Part I., chapter i., section 3; it consists of a band of iron plate, carrying pieces of hard wood, both ends of the iron strap are connected to a lever at points about two inches apart, so that the blocks of wood are made to press against the circumference of a smooth drum, fixed rigidly on the same axis as the drum turned by the cable; the pressure is regulated by the force applied to the actuating lever. From the brake the cable passes to the dynamometer; this consists of a weighted jockey wheel having a deep groove on its edge to receive the cable; the axis of this wheel is movable in a vertical frame, so that the wheel may rise or fall within certain limits; on the frame a graduated scale is marked, on which the height of the axis of the jockey wheel can be read off; the jockey wheel rests on the cable, and being weighted, it bends the latter; from the degree to which it does this the tension on the cable can be calculated. If *abc*, fig. 83, be a portion of the cable, and *b* be the jockey wheel depressing the cable midway between the pulleys *a* and *c* through the height *db*, let $m =$ weight of jockey *b*, $x =$ tension of cable between *a* and *b*, then—

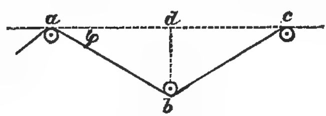


Fig. 83.

$$x \sin \phi^\circ = \frac{m}{2}, \text{ or } x = \frac{m}{2 \sin \phi^\circ}.$$

If $n =$ distance $ad =$ half of ac, and if $q =$ the distance db, then—

$$\sin \phi^\circ = \frac{q}{\sqrt{n^2 + q^2}},$$

substituting this value for $\sin \phi^\circ$ in the value of x—

$$x = \frac{m\sqrt{n^2 + q^2}}{2q} \therefore q = \frac{mn}{\sqrt{4x^2 - m^2}}.$$

To make a scale for measuring the tension on the cable by the vertical depression *db*, assign different values to x in the last equation; as m and n are known quantities, the values of q for the several values assigned to x may be readily calculated. The cable passes from the tank round the brake drums, then under the jockey of the dynamometer, and finally over a pulley fixed over the stern of the ship into the sea; a man stationed at the dynamometer has control over the brake, and can thus control the tension. The above is a general description of the apparatus and manner of conducting the operation, generally two drums and two brakes coupled together are used, one brake acting on each drum; an apparatus is attached to register the length of cable actually passed out by recording the revolutions of the brake drums, or those of a pulley turned directly by the cable, and pumps are conveniently situated for keeping the brakes cool. The lever actuating the brake may be weighted or acted upon by hydraulic pressure; in the latter case it is connected to the rod of a piston working in a hydraulic cylinder, and by putting pressure above or below the piston the brake is tightened or loosened as necessary. The trim of the ship is commonly preserved by taking in water as ballast as the cable is exhausted. The machinery should be of the best and most solid construction, and the brakes should be sufficiently powerful to stop the cable. Besides the control over the tension furnished by the brake, the dynamometer acts as a spring on the cable to ease it when from any cause the tension is suddenly increased or diminished. The angle of immersion is also an important element to observe, this angle is usually so small during paying out that the pitching of the ship scarcely affects the tension, but when this angle is large the pitching of the ship affects the tension sensibly, its influence is a maximum when this angle is 90°, and becomes considerable when the cable is fixed at the bottom, as may occur in raising a cable. This angle of immersion also indicates by its magnitude the rate of sinking when the rate of the ship is known, the length of cable sinking at the same time when the depth is known, &c. The object to be attained is to lay the cable for its whole length on the ground, that no part may be suspended between elevations on the bottom—*i. e.*, to lay it so that there may be no tension on it at any part when laid; and to lay sufficient slack to ease the cable in passing out as much as may be necessary, to admit of it being lifted should such become necessary, and yet to so limit the excess that the cable may not get into kinks, or the line be unnecessarily lengthened by which the cost would be improperly increased and the rate of signalling reduced. For a depth of 2,000 fathoms

16 per cent. is sufficient slack, but 20 to 25 per cent. is not excessive; a cable has been laid in 30 to 35 fathoms with less than 5 per cent. slack, but this is very exceptional. The percentage of slack necessary to admit of the cable being raised on the bight may be calculated when the depth and nature of the bottom are known, and the force required to drag a unit length of the cable in water on similar material to that of the bottom has been ascertained by experiment. It is easier to pay a cable out taut than slack, as when taut it is less liable to a certain class of accidents, as kinking; for the same reason a somewhat stiff cable is preferred to a very flexible one, and if the coils stick together somewhat it tends to hinder the cable from jumping. The route for the cable having been carefully sounded, the tension on the cable must be adjusted according to the depth and other conditions present at each stage of the operation. Cable ships should, if practicable, be large enough to contain the whole cable to reduce the number of joints. The "Hooper" and "Faraday" are the only vessels actually built for the purpose, the latter can carry 5,000 tons, equal to 1,500 miles of thin cable, it has three tanks, two 45 feet, one 37 feet diameter, and each 27 feet deep; the testing room is conveniently situated in the corner between the two main tanks. The machinery on these vessels is of the most solid description, and the testing rooms are fitted with strong furniture; batteries for use at sea are fitted in stands or racks, and covered with paraffin or other suitable material to prevent the liquid being spilt by the motion of the ship.

446. When a short cable has to be laid in a river or a narrow arm of the sea, there is no cable-laying vessel on the spot, and the expense of procuring the use of such a vessel is too great compared with the value of the cable to admit of its use; then a vessel procurable on the spot must be employed for the purpose, and the appliances at command employed in lieu of the more perfect machinery. In shallow water very little difficulty is experienced, the cable may be payed out by hand, it must be paid out slack or the boat will not steer, and will thus be borne along by the current if there be one. The slack in this case is of great utility in case of scour, a common occurrence in rivers; and as shallow water cables are liable to accident from currents, anchors, &c., the slack is very useful in case of repairs being necessary. It is evident the proportion of slack to admit of repairs must be larger in a very short cable than in a long one under conditions precisely similar, excepting in the particular of length. Across very shallow water, as in landing the shore ends of deep-sea cables, the cable is laid by men wading in the water.

When a boat is used in a strong current, kedging may be resorted to. In all cases a strong boat should be chosen, as much way as possible should be put on it, an anchor and means to stop the cable should be ready for use in case of accident. When comparatively narrow deep water has to be cabled, considerable propelling power in the vessel is necessary, for in this case tension consequent on the depth has to be resisted, and the conditions are those described in the case of deep-sea cables. If the tension be such that the cable cannot be held directly, it may be passed round a drum and friction used to increase the control, the friction of the cable against the drum may be used instead of the brake described in the case of long cables; the drum should be of large diameter and kept cool by water, it may be made by covering a windlass or capstan with timber or iron, the operation should be performed slowly, as risk of accident is thereby diminished. This is only applicable to very short cables, as the cable wears away the surface of the cylinder; it is but a rough expedient, and damages any preservative coating which may have been applied to the cable. Another form of brake may be made by making the cable pass between blocks of wood pressed together by a lever. In using the friction of the cable against wood, the wood is rapidly worn away, and this must be considered and provided against in improvising machinery. It is far better when possible to imitate roughly the machinery used for long cables; instead of acting on the cable directly let it turn a drum or roller and apply the brake to the roller, distributing the pressure over a considerable surface. If the cable be passed over the stern of the vessel and allowed considerable lateral play, it interferes less with the steering than if confined by being passed out over a sheave, but in the former case if allowed to rub against the woodwork it rapidly cuts it away, and means should be provided to prevent this—stout iron plate or a long roller may be used. To stop the cable if the brake is not sufficient, a few turns of a rope may be put round it, the rope being fastened securely by one end to a timber head, this rope is kept free until it is necessary to stop the cable when it is drawn tight. Rope may be used as a brake, the rope being worn away fresh rope must be applied from time to time. To lay a cable in a river choose a strong roomy boat; the boats used by the natives of India are usually unfitted to bear a concentrated cargo, or such strains as those consequent on lifting or suddenly arresting a cable running out; the crew should be a strong one, and as the boat will not steer well a second boat is as a rule necessary; the cable should not be confined by a sheave, it should have considerable lateral play to reduce its influence

on the boat's movements. The path to be followed should be marked by ranging poles on the banks; if the river be wide floating marks may be used, if practicable prominent objects on the banks, such as large trees, should be used to steer by. The cable, previously carefully coiled in the bottom of the boat, should be paid out by hand, great care being taken to prevent accident to the men engaged, particularly to make them keep clear of the centre of the coils as they rise and are drawn straight; coolies not used to the work are sometimes very careless. The depth of water, momentum of vessel, and strength of cable are usually such that there is no danger of injury to the cable if the paying out be suddenly stopped, there is no necessity for apparatus to indicate tension or rate of running out, and the cable must be laid slack or the motion of the boat will be impeded. If the current be strong the operation is rendered more troublesome, and in most cases the boat may be taken over the track once or twice with advantage before actually paying the cable out. There is difference of opinion concerning the slack which should be allowed in river cables, but in general they should be laid very slack, apart from the necessity for laying them slack consequent on the manner of laying them. If the bottom and banks of a river are stable, and there is no risk from vessels anchoring near the cable, then the cable need not be laid very slack, and a few turns of cable buried on the bank to provide for possible splices is all that is required. If the bed of the river is unstable, then the cable should be slack to allow it to rest on the bottom after scour; as river cables sink in silt and become buried and covered with weeds, unless slack they cannot in some cases be raised even in shallow water. The cutting of banks when high and steep frequently exposes the cable and strains it, hence near such banks the cable should be very slack. Cables are less liable to injury from small anchors if slack, and in extremely unstable rivers, notwithstanding the objections to very slack cables, the only chance of keeping up communication is by laying a very strong cable very slack, otherwise the cable fails immediately the stream is flooded; this is the general result of experience in India. A short cable should have a greater percentage of slack than a long one, to allow for splicing. A small coil of cable should as a rule be buried on one bank. Ordinarily 10 per cent. is sufficient slack in a slow current, and with a fairly stable bed, when the river is very unstable the more slack the better, if it can be laid in a serpentine line and prevented from kinking; if the banks be high, vertical, and unstable, a few coils of cable should be buried on each bank. River cables are easily laid, but very liable to accident afterwards, and are frequently so buried

in a short time in the mud or covered up by scour that they cannot be taken up for repair; hence great judgment and a careful examination of the river are frequently necessary to choose a site, and in some tropical rivers a cable will not last longer than from the end of one rainy season to the beginning of the next. In India rivers move occasionally to new channels, some of them are always very unstable, both bed and bank; the bank at one place may be carried away for perhaps two or three hundred yards in twenty-four hours, and at another spot vast quantities of earth may be deposited; in a very short period the depth may increase at one place 40 or 50 feet, at another place it may decrease to the same extent; in such rivers cables cannot be picked up, and they are required to be very strong and laid very slack. Extensive alterations of river beds cannot be provided for in laying cables or erecting masts; most great changes are either gradual or their imminence becomes apparent before they take place, and the real source of security is careful periodical inspections of the stream, and anticipation of the changes by shortening or lengthening the cable when practicable, removing the masts, &c. In order to do this effectually the stream should be inspected for some distance before laying the cable, and inquiries should be made concerning past changes; after a cable has been laid or masts erected, a plan and section, should be recorded shewing the form and position of the bank and positions of the ends of the cable or masts; a few measurements made from time to time will render alterations evident, and the particulars of such measurements, or revised plans and sections should be recorded with the original drawings. A short distance on each side of the crossing should be included in the plan. When a cable is laid across a very wide river or an arm of the sea, from a small sailing vessel or steamer, it is necessary to have more control over the cable than when laying it from a boat, as the water is as a rule deeper. The vessel should be driven slowly; if the cable cannot be controlled by hand, then the machinery used for long cables should be imitated; in all cases the channel should be sounded and the tension calculated for the proposed velocity of the vessel, percentage of slack, &c., before commencing the operation; and fine calm weather should be chosen—a matter of little difficulty, as the operation does not as a rule take long. Although many of the difficulties experienced in laying deep-sea cables are absent others are present, and from the imperfect machinery usually available there is often considerable risk in laying a cable in this manner.

447. A cable may be raised either from one end, as in case of accident during paying out, or when the operation is commenced

from the shore, or it may be commenced from an intermediate point when a fault has been localised by testing after the cable has been laid. The operation in either case is comparatively easy if the water be shallow and the cable is not buried in sand or mud or entangled in aquatic plants. The machinery for raising the cable fitted on board cable ships is of two kinds—in one kind the cable is lifted by separate machinery on the principle of the ordinary steam winch, being transferred to a sheave over the bow of the ship for the purpose; in the other kind the brake drums are driven the reverse way, the cable may be transferred to a pulley at the bow, or the ship may move backward. Of the two ships built expressly for cable laying, "the Hooper" steers only one way, and the cable has to be transferred to the bow when it is to be taken in; "the Faraday" may be steered from either end, and the cable does not have to be transferred—the ship is steered from the other end and moves backward without turning when the cable has to be taken in. To raise a cable on the bight it is first grappled, by causing a vessel to drag a grapnel across the line of the cable until it is caught; it is then slowly brought on board. An ordinary grapnel may be used, but for raising deep-sea cables a more complicated grapnel has been devised; it differs from the ordinary form in having arms from the shank to the flukes, which close automatically and prevent escape of the bight after it has been seized. When the depth is considerable the cable may be caught on the bight and broken, then a second bight may be taken on one side of the break; in this case the angle of the bight raised being reduced by first breaking the cable, the tension on the cable is greatly reduced. Or, instead of proceeding as described above, two or more bights may be taken up by different vessels so as to reduce the angle of the bight lifted from the water. An improved grapnel has been invented by Mr. Lambert, by means of which a cable may be grappled, broken on one side, and raised from the other; this grapnel has been successfully applied. In taking in the cable the ship should move slowly over the path of the cable as indicated by the cable itself, and the cable should be coiled away by hand as it is received on board.

448. Joints in cables are technically termed splices, because the guards are spliced in a manner somewhat similar to a long splice in a rope. The joint may be divided into the splicing of the guards, the joining of the accidental materials as the hemp serving outside the guards and the packing between the core and the guards, joining the insulator, and joining the conductor. Joints in the insulator are made as described for gutta-percha or India-rubber core, as the case may be. The hemp or other

packing or serving is unwound when commencing the joint, and put on after joining the core or guards, as the case may be; it is not, however, opened in single yarns, but in parcels each of one-third or one-fourth the total number of yarns used, so that the yarns are opened in three or four separate parcels. They are served on as nearly as possible as they were originally; they are thinned out if necessary, are made to break joint, and tarred or otherwise treated according to their original treatment in the manufacture. Packing when replaced should not increase the diameter of the served core beyond its original length, or the guards will not lie close—hence it may be necessary to thin down the yarns; but the same necessity does not exist in the case of the covering put over the guards. In shortening the core the packing should not be shortened to the same extent; enough should be left to cover the whole length of served core from which the guards are removed in making the joint. The guards are spliced on the same principle as a long splice is made in an ordinary rope, each guard not being joined but merely laid in between the others; but practice differs in the two cases. The case of a cable differs from that of a hempen rope in the following particulars:—The twist being much longer in the cable the splice must be longer to hold; in practice it varies between 20 and 60 feet; 30 feet is sufficiently long in a cable covered with twelve wires not larger than No. 3 B.W.G.; the strands in a rope are only three in number, and very flexible; whereas the guards of a cable are seldom fewer than twelve, are comparatively inflexible, and when bent the twist is readily lost. Hence in splicing the cable the following precautions have to be observed:—1. The guards of the cable are opened in three or four parcels instead of singly, and each parcel is temporarily tied with twine or wire to keep the wires together; 2. care is taken to prevent the wires being bent, by being trodden upon or otherwise, by which the twist in them would be spoiled; 3. as the wires are so numerous, and require to be carefully handled, it is found convenient to open the guards of only one of the ends of the cable, in the first instance, instead of both ends, as with a rope—thus the splice in the guards is on one side only of the conductor joint, and is made by laying the whole of the guards from one of the ends to be joined into the other, not by laying in a guard alternately from each end, as in splicing a rope. The splice is made in the following manner:—Straighten carefully the ends to be joined; if the guards are uneven or otherwise damaged at either end, put on a short serving of thin wire, and saw off the damaged piece with an ordinary metal saw; separate the guards of one of the ends to be joined into three equal

parcels, or if necessary four; separate these guards from the core for a length two yards or more longer than the splice to be made, temporarily tying each set with twine or thin wire to keep the individual wires together; avoid injury to the twist; shorten the core from this end, leaving a length of 3 or 4 feet only for jointing—this length is left in order that the separated guards may not be inconveniently near, so as to be in the way while joining the core, and for convenience in jointing the packing. The other end to be joined is prepared by putting on a serving of wire, sawing off the guards flush with each other, so that 1 or 2 feet of the core projects beyond the guards; as the guards are less in the way a shorter length of core is necessary on this end. The conductor and insulator having been joined, the serving over the core is replaced, being made to break joint as much as possible; put on tightly, and so as not to exceed the original size of the served core. The joined cable should be now slightly strained by hand to straighten the core, and held straight by men for a somewhat greater length than that of the splice, the serving on the shortened guards is removed, one parcel of the long guards is taken, arranged parallel with the cable, and an equal number of wires being selected and unwound, this parcel is wound on in their place; but in sawing off the wires they are not cut off at one place, but 2 feet or more apart—thus, if each parcel consisted of four wires, when these were laid in and cut off they would meet the guards of the other side at four places 2 feet or more apart. If the cable had twelve wire guards and the joint was 24 feet long when the splice was finished, the guards of one side would meet those of the other respectively at twelve places 2 feet apart, distributed over the 24 feet, the length of core uncovered to make the joint would be 30 feet, and the joint in the core would be on one side of the long splice in the guards. The guards should meet well and should be well faced at the ends, not pointed or sharp, and a serving of thin wire is put on for 6 inches to 1 foot over each place where the guards meet. If a strand rises in splicing, it should not be hammered down, or the shape of the cross section of the cable may be altered, the core may be injured, and the correct abutment of the guards destroyed; to lay the strand the cable is seized by a heavy pair of tongs somewhat resembling pincers, these are driven along the cable over the raised strand by a hammer, and the strand is thus pressed down without altering the cylindrical form of the cable. Cable conductors are joined in two ways—in one the strand wires of each end are soldered to form a solid and are filed down for scarfing, the two ends are then placed together, served with fine wire, and again soldered finally; another serving of fine wire

is put on extending beyond the first serving on each side and soldered only at its ends, in order to maintain the electrical continuity if the joint opens out. The fine wire is commonly put on several turns at a time rather than singly, but the several turns should be as evenly laid as a serving of one wire. This joint is very rigid, and probably usually much weaker than the unjoined conductor. The other mode of joining is as follows:—Two or more twists are put into one or both of the ends to be joined by coiling the core or cable on the floor, the strands of the conductor are now separated for a short length on each side, the ends of the wires on one side are separately joined to those on the other by a simple scarf without binding wire, and so as to break joint, the two or three extra twists put in by coiling are then concentrated in the joint. This joint is superior to the scarfed joint, but it takes a greater length of conductor, and hence makes a longer joint in the insulator; its strength is due in a great measure to friction, hence the joints in the single wires should be at least half an inch apart. It is more flexible than the scarfed joint, is better suited to a conductor of three than one of seven wires, and is not applicable to a conductor consisting of a thick central wire surrounded by a number of thin wires. The scarf joint is more commonly employed. An excellent joint might be made in a stranded conductor by simply laying the wires together so as to break joint (as in splicing cable guards), and soldering the whole length of the splice.

449. Cables are coiled so as to put an extra twist into them, this is taken out in uncoiling, and the cable is laid therefore in the state it left the spinning machine; but it reaches the bottom with a slightly less twist when laid in deep water. Cable core is in some cases tested by subjecting it to pressure under water, the pressure to which it will be subjected in the sea or a more intense pressure being put on it for a time and the effect on insulation noted, generally the core is first subjected to a partial vacuum; but although of great importance to discover the effects of pressure in the first instance, the practical value of such testing is very doubtful. Gutta-percha cables covered with iron guards if once wetted must be kept under water, as the heat developed by oxidation of the iron is so great as to soften the insulator, and injure the cable. Gutta-percha cables are usually kept under water, and are kept under water in the ship from which they are laid. Cables of Hooper's material are not liable to injury from heating, and they may hence be exported dry without fear of injury, this is a source of economy; the cable is coiled on board ship, the coils being merely separated by planks, but gutta-percha cable should be packed in water tanks.

The sites of cables should be marked by masts carrying discs, flags, or other signals, when it is necessary to warn vessels from anchoring too near; in India the sites of river cables are marked by small masts carrying discs painted red—notice boards on each bank and at any landing place or market near explain the meaning of the signs and warn the boatmen; this is found sufficient, as the result of catching the cable is always inconvenience, and with boats frequently the loss of an anchor.

SECTION V.—*Fittings and Arrangement of Offices.*

450. Underground wires are connected directly or by covered wire with the commutator or testing board; overground wires are stopped at the terminal insulator, and should be brought under shelter by well insulated uncovered wires, as covered wire does not bear exposure, and unless frequently renewed its insulation cannot be depended on. The wires joining the line outside to the wires inside the building are termed the leading in wires, they are usually of thin wire (12 to 18), and insulated by small insulators similar to those used on the lines but smaller. Office wires are mostly of copper, but iron wire is sometimes used and might be used more commonly; the objections to its use are its greater rigidity and the greater difficulty of cleaning it; for covered wire copper is as a rule better. For short circuits, as in the small offices in towns connected with local lines only, wire covered with cotton may be used; for connections with long lines covered connecting wires should be well insulated—gutta-percha is used to cover these in temperate climates, but in tropical climates gutta-percha is inadmissible and India-rubber is used. Well varnished cotton might in some cases be used with great economy for fixed wires. Thinly covered wires only are required for office connections, it is not necessary to put on the thick coating of the insulator sometimes used for underground wires; a thick coating increases greatly the cost of the wire and the volume of the wires, the latter is an important consideration when a great many wires have to be fitted. For battery wires and also for other wires on short circuits, or when a very high degree of insulation is not attained on the lines, uncovered wires may be used, insulated by small rings of white porcelain; but it is difficult to dispose of uncovered wires if numerous, hence thinly coated wires are preferred, and when a great many wires have to be disposed about a building these are more economical, as they can be tied in bundles, and then occupy comparatively little space. Uncovered wires may be used most economically in small offices having very few circuits, in which the wires can be

conveniently fixed to the walls on wooden battens. For earth wires uncovered wire may be used, for lightning dischargers and when to be laid on the floor, strips of sheet copper are very convenient. All wires should be joined by soldered joints as far as practicable, binding screws are expensive and the contact is inferior; permanent twisted unsoldered joints ought not to be permitted. Joints which have to be opened are joined by binding screws; a piece of copper with a slot in it to receive the screw soldered to the end of the wire, is better than bending the end of the wire round the screw when a contact has frequently to be opened. Hooks on wires to pass round binding screws should be right-handed, in order that they be not opened in screwing down the nut. The ordinary bellhangers' joint is used to join copper wires. Wires when few may be fixed to the walls so as to be visible, but it is better to lead them about a building by tying them in bundles or cables properly labelled, and enclosing them in troughs or tubes, or merely placing them under the floors or along the walls. In Europe and America the wires are generally hidden away and cannot be got at excepting by a carpenter taking up the floors, &c.; in India the wires are arranged to be accessible throughout their whole extent for inspection: the difference in practice is due to the fact, that gutta-percha used for insulating the wires is very durable in Europe, many wires in office connections are apparently perfectly preserved after fourteen years use, but in India the wires covered with gutta-percha were quite untrustworthy, and the frequency of faults in the wires rendered it necessary to have them accessible; India-rubber used at present is more durable. In Paris the wires are made into cables, one cable leading to the instruments in each room; in England the wires from the connection board are made into a cable, and from this small cables branch off in different directions, the whole being placed under the floor. In the Berlin office the wires are brought in as cable, but in the instrument room they are all visible—they are uncovered and supported by brackets on the instrument tables. Wires made into cables are less liable to injury, the covered wires are simply placed together and well served with tape, which in the case of gutta-percha covered wire is soaked in Stockholm tar. The practice of making the wires up into cables would be found very suitable for tropical climates, as it would tend greatly to preserve the insulating material, to protect the wires from mechanical violence, and render it easier to arrange them about the building without making them inaccessible by placing them under the floors, and this mode of disposing wires is cheaper than fixing them against walls separately. Covered connecting wires should be protected

from the light when possible to increase their durability; if tarred or painted the tar or paint should be occasionally renewed. Although not usual in temperate climates, in tropical climates it is very advantageous to have the wires or cables accessible throughout their whole extent; but it is better to prevent accident than provide means of discovering faults, hence it is preferable to make up the wires into cables, than to leave them loose or fix them separately, particularly when they are very numerous. In making wires into cables they should be placed parallel not twisted together, and they should be classified—*e. g.*, the wires for each room may form a separate cable, or the battery wires may form separate cables from the line wires; the wires in a cable may differ in size, those for different purposes differing in size and being thereby distinguishable readily. All wires should be numbered or labelled at each end for convenience in testing them or altering connections. Connecting wires should be as short as practicable.

451. In some offices large commutators are used, in others the commutator is replaced by a testing, terminal, or connecting board; in the new offices of the Western Union Telegraph Company (America) is a commutator, probably the largest in existence, it is in three sections, forming each a separate commutator, each section contains 54 upright straps; the whole arrangement provides for 132 wires, it is 3 feet wide, 12 feet long, and contains 16,000 pieces. In India commutators are used, but the largest provides for only about 12 lines. In England commutators are not used; in the central office at London one large testing board is used, it will provide for 800 lines, and consists of a flat surface of woodwork carrying screws arranged in pairs, one of each pair being connected with the lines, the other with the instruments; a row of knobs projecting from the board serves to support wires used for making transverse connections, for which ordinary covered wire is used. In the battery room smaller connection boards are used. In the central office at Paris the line wires are brought into one room to a set of binding screws arranged in a large circle on the wall; another set of screws arranged in a concentric and smaller circle is connected with the instruments, and these two sets of screws are connected by wires arranged radially. The battery wires are brought to a line of screws, and connected by uncovered wires in porcelain rings to a second set. From the rooms containing the arrangements described the wires are distributed to the instrument rooms, those for each room are made up into a separate cable; the instruments are distributed over many rooms, in each room is a small connection board having two vertical

rows of binding screws, one connected with the lines, the other with the instruments, the connections are made between these two rows of screws by flexible conductors covered with vulcanised India-rubber and of suitable length. In the Berlin office a commutator is used providing for 96 lines. The commutator is very useful for a small number of lines, not exceeding perhaps 10; when larger it becomes inconvenient and unnecessarily expensive, and the connection board appears more convenient. The commutator provides more than is required, it appears useful for a large number of lines only when divided—*i.e.*, the instruments being arranged in groups, a separate commutator is used for each group. The arrangements in use in London and Paris appear preferable to the use of large commutators. When a testing board is large, to save trouble in tracing connections all cross connections should be labelled at each end. On testing boards all cross connections are recorded as made, and at a certain hour every day they are either taken off, or the reason for leaving them on is recorded. The arrangement of the Paris office seems to offer many advantages over the use of one large testing board, as the long wires used for making cross connections are dispensed with, and the arrangements can be seen without tracing out connections; but in the case of a large number of lines, as in the central office, London, this plan cannot be carried out.

452. In Europe the protection from lightning is not required to be so perfect as in India; in France and Prussia point dischargers are used at each instrument; at Paris the lines as they enter the town pass through a small building in which a set of dischargers is arranged, the same building serving for testing purposes. In England the small grooved plate dischargers are used. In India large surface grooved plate dischargers and thin wires are used, these are covered with glass cases and are open to inspection; a point is frequently attached to the line and brought near the terminal post, a copper disc is soldered to the latter to receive the spark.

453. It is common to have the instruments arranged either in one or several large rooms, a large number of instruments when possible being placed in the same apartment; an exception to this is seen at Paris, the ends of the lines are brought into one room, in this room there are no signalling instruments, hence any examination of the lines can be carried out in this room without disturbance, and without interfering with business; from this room cables lead to many other rooms, and instead of a very few large rooms the instruments are arranged in small rooms, each room containing a convenient number of instruments properly classified geographically; a chief clerk has charge of one

or more rooms. The distribution of instruments over several rooms rather than massing a large number of them in one room has many great advantages; the signalling clerks are more under control, the arrangement of connections simpler, the noise and apparent confusion are less, messages can at all times therefore be received by sound—testing and other technical operations being carried on in a separate room interfere less with the business of despatching and receiving messages, &c. At the central office at London all the instruments are in one room having an area of 20,000 square feet, and containing two-thirds of a mile of mahogany tables, the number of clerks employed is about 1200. Having inspected many offices, the author was struck with the absence of noise and the other great advantages of the arrangements at Paris. Instruments should be arranged geographically; at translation stations instruments working together in "translation" should be conveniently placed for the purpose.

454. Batteries should be arranged in a separate room from the signalling instruments whenever practicable, they are best arranged on shelves made of wood well soaked with drying oil, when numerous they are usually arranged on racks or frames of oak, teak, or pine. The battery room is most conveniently situated when in the basement of the building. Soldered connections should be used as far as practicable in preference to binding screws.

455. Testing apparatus is usually arranged conveniently near the connection board or commutator, it should be connected by permanent wires in such manner as to be available at any moment. It is better to have the testing arrangements in a separate room from the signalling instruments.

456. Messages are conveyed about the building in small offices by hand, but in large offices tubes containing small buckets are very commonly used between different stages. In London, messages were formerly conveyed about the building by endless bands of tape kept continually moving, and the message was simply inserted between the bands, by which it was then conveyed and shot into a small tray in the part of the building where required. The system of endless bands has now been superseded by one of pneumatic tubes; short tubes are laid, they are controlled from one end only, and by this means the messages are conveyed between different points in the instrument room. In the Berlin office messages were (1864) conveyed between different stages by tubes, the carriers were caused to ascend by pneumatic pressure produced by a man acting on a pair of bellows by means of his weight; the tubes were polished inside, and the carriers were covered with chamois leather and

fitted the tube loosely. Pigeon holes and boxes to contain messages at the signalling instruments should have covers of glass or be simply cages of wirework, the latter serve the purpose very well; the object of these precautions is that the messages may be seen and not be overlooked.

457. In general the furniture should be strong and not likely to harbour dirt or insects; solid wood well polished is the best, and baize and leather table covers should be avoided. Sometimes several instruments on the same table are separated from each other by glass screens; these are inconvenient, but a small batten three or four inches high may be used with advantage. Separate tables are perhaps the best for terminal stations, for translation stations each table should carry two instruments. Commonly several instruments are placed on one large table. The tables should be large enough to allow about 9 square feet to each signaller. All instruments should be well covered up from dust by glass covers; commutators, testing apparatus, lightning dischargers, &c., should be enclosed, preferably in glazed cases. The ventilation should be good; as the men have to work all night, it should be provided for without draughts; it should not be under control of the clerks.

458. Plans should be made of all large offices, shewing the disposition of the instruments, distinguishing the kind of instruments, shewing the positions of the several tables, distribution of connecting wires, &c.; for small offices isometrical projections may be used to exhibit these details. These plans are usually filed in the office of the engineer in charge of the section, but they are useful to the clerk in charge, and are particularly useful to a stranger assuming charge. Traffic routes, representing the lines round the office and contiguous offices in a conventional or ideal drawing, are also of great utility. The lines of a system are usually distinguished by numbers. Sometimes the whole telegraph system is divided into sections, each section is a length of line between two important towns usually having much through traffic; to the section is given a distinguishing number by which the circuit is known at every part of its course, and by which it can be referred to. Sometimes one or both of the termini are mentioned with the number, but the number is sufficient. A list of the numbers of the circuits is printed; it gives particulars of the route of each and other particulars, and this list is revised from time to time as new circuits are added or old lines dismantled. In England the circuits communicating with the central office have each a distinguishing number, given by the authority at the central office, and the same authority can alter or modify the circuits, such changes of designation being

binding on other offices. When the instruments are numerous, at each one is placed a label stating the number of the circuit, its other terminus and offices, and the manner in which the lines are ordinarily connected at each of the latter, as "direct" or "translation." The distinguishing number given to each circuit is kept by this circuit irrespective of variations of gauge, position on posts, &c.; it refers to the particular circuit, and particularises the whole of the circuit. If a portion of one circuit is inserted in another this does not become part of the second circuit, it still retains its distinguishing number; the new disposition of the lines is carefully recorded, and within 24 hours the wires of the two circuits are either separated, or the reason for allowing the temporary arrangement to continue longer is recorded; as early as practicable the circuits are separated. If however, one section of a circuit be faulty, and it be necessary to make a permanent alteration, such alteration is made and the circuit is reconstituted by order of a central authority, it being necessary to confine such powers to one central authority to prevent confusion. The lines on each post are known by an arbitrary system of numbers, but this merely distinguishes the position of the line on the pole. As, however, lines usually maintain one relative position on the poles throughout their entire length between two contiguous stations, when few in number the circuits may be distinguished between such stations by the numbers representing the relative positions of the wires on the poles; but these numbers must not be confounded with the numbers distinguishing the circuits when a separate set of numbers is used for this purpose, the commonest case in practice.

CHAPTER II.

MAINTENANCE AND ORGANISATION.

SECTION I.—*Repairs.*

459. REPAIRS may be classified as those to prevent interruption of telegraphic communication and those to restore communication when interrupted by accident. Work of the second class is reduced in proportion as that of the first class is well

done and possible causes of accident foreseen and provided against. For work of the second class an establishment must be ever in readiness, the tools must be of the lightest and most portable description, materials of certain kinds, as insulators and wire, must be readily accessible, and the work must be done quickly, regardless of its cost and durability; any temporary expedient is admissible, the materials used may be perishable or borrowed for the occasion; and generally the necessity for rapidly restoring communication renders the work more costly and makes it necessary to do the work over again in a permanent manner, so that the cost of such repairs is loss—*i.e.*, no permanent advantage is purchased—*e.g.*, a line damaged by a storm may be repaired quickly by buying bamboos on the spot for posts, making unsoldered joints in the wire, dispensing with insulators, perhaps inserting rusty wire or thin copper wire in the line, &c.; on the arrival of materials all the work of reconstruction has to be done over again, and the materials purchased for the temporary purpose are perhaps thrown away, not being saleable or worth carrying away. It is manifest repairs of the second class are unprofitable, and however short the interruption of communication, it is far more economical to prevent accident as far as possible than repair damage quickly at any cost. Interruptions damage a line commercially and cause a direct loss in traffic receipts, hence no pains should be spared to prevent them by anticipation.

460. Materials for repairs should be carried or stored at intervals; insulators are most often required, and a few should be distributed at villages, towns, cable huts, police stations, &c., for emergencies, every 10 or 12 miles is near enough for depôts, and 2 per cent. is a sufficient number on an average; a small quantity of wire, a few bracket bolts, and other similar small stores, should also be deposited. In constructing a line a few articles are usually left at depôts, but the quantities should be kept down, and the greater part of the surplus stores should be kept at the telegraph offices; a few posts and 2½ to 5 per cent. of wire should be held in reserve. At long river spans a second span wire should be stored near the span for use in case of emergency. If many short river cables occur near each other a reserve cable may be kept to provide against accidents. As a rule a working party repairing a line should be fully provided with an assortment of every description of article used on the line, and should be prepared not only to do any slight repairs, but to reconstruct or alter any short section of line, so that no defect of any kind may be left to be repaired at a future time. As a rule it is

cheaper to cart an assortment of stores than allow stores to be deposited on the line for future use, for if the materials are actually with the party there is no excuse for postponing the execution of work, and the cart is usually necessary to carry the men's luggage. On railway lines smaller quantities of material may be carried, but even in this case a complete assortment should be carried from station to station when a line is to be thoroughly repaired. Heavy tools should be deposited at depôts on the line, if there are any cable huts or other conveniently situated and secure means of storing them; ladders should be rather left at line depôts, as they are inconvenient to carry. For permanent work heavy tools should be used, for restoring communication light portable tools and very light rope and blocks; the whole should be carefully packed for use at any moment, and on no account should light tools be used for permanent repairs—firstly, because they might be missing when urgently required; secondly, because they are quite unsuited to heavy work, and if used for such are soon rendered unserviceable. The percentage of stores of each kind which must be held in reserve depends on the circumstances of each case, and should be found by experience; if insulators are removed as soon as they are cracked however slightly, 5 per cent. is not found too large a percentage in India for ordinary flat country stores being issued once a year, this leaves a small percentage always on hand; the consumption may however reach this figure, and on hilly country exceed it. The insulators are presumed to be hooded.

461. As a rule inspection of lines, without the means of immediately remedying the defects discovered, should be avoided as a source of expense. Lines should be periodically examined and every defect, however slight, removed. The inspection of long direct lines should not be made by regarding them from an adjacent road; men with ladders should examine every insulator bracket, lightning discharger, contact wire, post, stay, &c., every pole should be examined for soundness if of timber, fastenings should be looked to, and the examination should be thorough. The inspecting officer should as a rule be accompanied by a sufficient number of men, and furnished with tools and materials to at once remedy any defects discovered; every broken or cracked insulator should be removed, the nests of insects, particularly such as those of the *termes*, certain ants, and the mason wasp, should be removed from the insulators, no discovered defect should be left unrepaired, the repairs should be executed under the eye of the inspecting officer if possible, and to prevent him being un-

duly detained he should be accompanied by intelligent foremen in order to employ a due number of men. In general the men should be in small parties or single, but when any alteration or other work requiring a large gang has to be done, they work together. An economical plan, when practicable, is to slightly increase the pay of several of the most intelligent workmen, and employ them to superintend; by this means a large party of workmen may be employed economically and the work done very quickly. A close network of lines in a country well covered with roads and railways may be kept in repair by a permanent staff of foremen and labourers; in this case the necessity for actually repairing the line under the personal supervision of the engineer does not exist, as the work may be readily inspected at any time; but more frequent inspection is necessary in this case, as small defects may be left unrepaired or the execution of repairs may be postponed from time to time.

462. The ultimate check upon the work is inspection by a competent officer; the expenditure may be controlled by being estimated beforehand, and by insisting on a sanctioned estimate for every work. The only check on the justice of expenditure and its necessity, is the experience of the engineers controlling the work and personal inspection.

463. The execution of repairs does not differ from construction so as to call for special treatment, it is frequently very troublesome to repair multiple lines without seriously interfering with traffic; in hot dry weather a line may be laid on the ground for a long distance without stopping traffic, this can seldom be done in temperate climates, but is general in India. Before removing ties or stays for repair or cutting out pieces of line, temporary stays or a temporary line must be erected; strong pickets are used as temporary anchors, and the straining tackle is used as a temporary tie, the load is taken off the permanent tie by hauling on the tackle fall. Not only should faults be remedied, but their causes sought out and removed—*e.g.*, if a tie at an angle is found loose the clamp may have slipped down or the anchor may have dragged; if the tie be tightened without removing the original cause, it will become loose again and ultimately perhaps fail by dragging up the anchor or otherwise. The sites of faults which have resulted in interruptions to communication should be examined, and alterations made if necessary to prevent faults in future. The work done to restore communication when interrupted may in the first instance be of a temporary character, but the man who executes the temporary work is responsible for making it permanent, for soldering all joints and restoring the

repaired portion to its original state; if beyond the power of this man to do the work permanently, he should guard the temporary work and be held responsible for it until the officer in charge can have the repairs permanently executed. Temporary work should never be permitted to remain on any line longer than necessary to make it permanent, and all work done after interruptions should be carefully inspected and the responsibility strictly enforced. Carts or trucks are as a rule necessary to carry tools and materials, and the men's kits should be carried for them. The inspection of railway lines from trains is not permitted in India, excepting to find faults which interfere with traffic, such inspection is very properly regarded as useless for other purposes. To restore communication on a railway line, it is merely necessary for the man to proceed until he passes the fault, alight at the next station and return to the fault; but when several faults exist, as sometimes on an Indian line after a cyclone, then a superior officer, with a party of men supplied with tools and materials, inspects the line, and at the station after each fault one or more men with proper materials and tools are left behind, and the whole line is inspected. If a fault has been localised by testing, the party despatched to repair it proceeds direct to the spot indicated.

SECTION II.—*Organisation.*

464. The establishment entertained for keeping lines in working order is organised either according to one of the two systems described below, or each system may be partially adopted. Under one system a small establishment of workmen is employed permanently to restore communication, patrol the lines, and execute all repairs as they become necessary over an allotted section of line or district; under the other system only the supervising officers and one or more artizans at each town or station are employed permanently—the former direct the working of the lines and direct repairs periodically; the latter are ever in readiness to restore communication when ordered to do so, employing labour on the spot or as near as procurable. Sometimes these systems of organisation are mixed—thus, the lines may be regularly patrolled by a set of men charged with the duty of executing petty repairs and reporting defects, gangs of men, employed permanently or temporarily, doing all other repairs periodically. Each system will be seen to have its merits. Under the first the lines are periodically inspected and

are *presumed* to be *kept* in repair, each little fault being repaired as it occurs, and interruptions are prevented by the frequent inspections; under the other system the labour employed is kept very low until actually required, and the establishment may be enormously increased immediately such increase is necessary—thus the cost of labour is kept down to its lowest possible limit, and as the repairs are done periodically by large gangs of men under highly instructed superintendence, they are better and more economically executed than when done from time to time by workmen whose authority to expend money and stores must be very strictly limited. One thorough inspection under strict supervision is more useful than many several inspections made at short intervals; for when inspection is made frequently there is a tendency to make it less searching, and to pass over slight defects. The lines are in all cases divided into sections arbitrarily termed districts, divisions, &c.; these may be subdivided, and the sub-sections suitably designated. The object of this division is to fix responsibility. In some administrations the traffic is carried on by one staff and the engineering details by another, and these duties are kept absolutely distinct; in other administrations the divisional engineers supervise the traffic and every detail within their divisions, and are responsible for both traffic and engineering. The best system on which a maintenance and traffic establishment should be organised must depend on the distribution and mode of construction of the lines, on the means available for the rapid carriage of labour and materials, on the supply of labour procurable on emergencies, on the honesty of the workmen, the climate, &c.; and in any particular case the establishment should be organised in accordance with requirements, and no particular system strictly adhered to. If there be separate superintendence for traffic, for accounts, for engineering, &c., men are answerable to several persons at the same time, details are arranged without reference to the total work required of each individual, and it is evident that either there must be multiple superintendence and consequent absence of economy, or the local authority must be weakened; hence as a rule there should be division of the lines into sections, the officer in charge of each section being responsible for every detail of execution and administration within his charge, forming a channel of communication between his subordinates and the central or superior authority, examining into the justice of complaints personally, and generally representing the central authority locally. The unit of charge may be lines and offices in a particular town, a certain length of line and the offices on

this line, or a very large office; but as a rule it is productive of inconvenience to separate responsibility for the lines from that for the offices, for if communication be unsatisfactory there may be difference of opinion, the line officer blaming the office arrangements, and *vice versâ*. The local officer need not necessarily perform all the administrative labour of his charge; thus the accounts may be forwarded to a central office for compilation, the traffic may be checked by examination of the messages by a special official, &c., care being taken to relieve the local authority as far as possible of excessive administrative work; but the local authority alone can by personal investigation fix the responsibility for abuses, enforce economy in expenditure, certify to the honesty of the accounts, &c. Estimates for repairs, for office establishments and materials, sanctions for the purchase of stores locally, &c., should be countersigned by the local authority. In a large office forming the charge of a local authority, the labour and responsibility may be divided under three heads—the technical details, the traffic, and the purely administrative—the latter including the receipt and payment of money and the preparation of accounts. When many employees are necessary the economy of this classification is very great, for signalling and mere clerical labour are very much cheaper and more abundant than electrical and mechanical knowledge and skill, and very few persons are sufficient to perform the purely technical duties in the same town or office, whereas a great number may be required to perform the labour under the other two heads—*e. g.*, in the central office in London 1200 signallers are employed, to insist on electrical knowledge and mechanical skill in so many is quite unnecessary; the technical arrangements are in the hands of a very few highly instructed officers and skilled mechanics, the signallers are mere clerks, technical knowledge beyond signalling is not required and consequently not paid for, the economy of this arrangement is obvious. It is highly desirable that the officer in charge of an office, however small, should know sufficient to at once remedy any defect in his connections and batteries, and understand the causes and nature of the accidents to which the apparatus is liable, but this knowledge cannot always be obtained; hence in some cases the offices in large towns are in charge of clerks entrusted with the clerical work only, the technical arrangements are in charge of a separate staff, and in case of derangement or any defect in the lines or office, the clerk in charge of the office communicates at once with the office of the engineer either by wire or messenger. This kind of arrangement is common in England, but it is only

practicable when there are many offices in the same town, and when there are facilities for rapid travelling. When the offices are distant from each other and the facilities for travelling rapidly do not exist, the officers entrusted with charge of the business of the office must be able to take charge of the technical details also; this is the case in India. There no one is entrusted with charge of an office who does not thoroughly understand the technical details; in case of accident to the lines the signallers are competent to go out and find the fault by cutting in on the line; several of the telegraph masters (clerks in charge of offices) display considerable knowledge and skill in testing the lines periodically and localising faults from the office. In every small office having only two clerks the second clerk is competent to take charge in case of illness of the first. It is manifest the system used necessarily in England cannot be used in India, where the offices are commonly a hundred miles apart, under these circumstances the officer in charge *must* perform the whole duty technical and otherwise of his office, and as he may be isolated from his superior officer, he must be not only well instructed in his duties but intelligent; hence it is necessary to educate a staff for the purpose. In large towns in most cases a class may be employed who are content to forego claims to promotion, higher pay, &c., on condition they be not transferred and not required to study technical matters; the employment of this class is generally economical, and is therefore common, but as already explained it is limited. For keeping the lines in repair an establishment of engineers and foremen must be permanently entertained to prepare estimates, supervise work, make periodical inspections, and generally perform all the superior functions essential to maintenance. The local authority already referred to may supply engineering knowledge, prepare estimates, periodically inspect lines, and superintend extensive repairs; the labour may be permanently entertained or employed as required. When the lines are thinly spread over a vast area, as in India and Asia generally, where work can only be carried on for five or six months in the year, labour can generally be obtained as required, and the rate of travelling is commonly slow, the employment of labourers in large numbers as required is most economical; generally many of the same men may be obtained every year, particularly if the sharpest are somewhat liberally paid. When a very great mileage is confined to a relatively small area, well furnished with facilities for rapid travelling, and work can be carried on all the year round, a permanent establishment of labour is more economical; this is

particularly the case in large towns where the lines are constructed in various ways, skilled mechanics, as carpenters, smiths, &c., being required to repair them. For restoring communication accidentally interrupted some men must be always in readiness to act at a moment's notice; if a permanent patrol establishment of workmen be entertained, each man or gang having a short section of line to keep in repair, this establishment executes urgent repairs on receipt of information from the nearest office; in large towns where a central permanent establishment is entertained this establishment may restore communication. In India one or more men are attached to each office according to the number of lines, facilities for travelling, &c., and this is the plan generally indicated when the offices are very far distant from each other; in the latter case labourers are engaged near the site of the work. To large offices, such as those of London and Paris, a workshop and skilled mechanics are attached for executing repairs, cleaning instruments, &c. As a rule the less instruments are interfered with by the clerks the better, for this reason it is more economical to allow spare instruments in large offices, than suffer the instruments to be taken to pieces by unskilful hands. Cables when numerous are usually kept in repair by a separate establishment.

SECTION III.—*Hints on Camping, Labour, &c.*

465. The following hints apply more particularly to India, but are more or less applicable to other countries, especially such as resemble India in the nature of their communications, the inferior civilisation of their inhabitants, &c. For telegraph work tents should be light and portable; heavy tents, difficult to pitch, are inadmissible, as they have to be moved frequently. Single pole tents are proportionally lighter than other forms, as will appear on calculating the superficial area of cloth in each case; the single pole tent is less liable to fall, and if well made and well pitched it will stand any storm, if it has not verandahs or other cloth arranged so as to catch the wind. The commonest tent in India is the hill tent, a square plan tent; it is more convenient than a circular tent, but in the latter the strain is more equally distributed, and this form is more easily pitched correctly. A tent should be simple in form, and the pegs should be placed regularly—*i.e.*, at equal distances from each other and from the pole. In pitching it is better to put all the pegs in

first by means of a simple measuring cord, and raise the pole and cloth afterwards. For servants and labourers the bell tent is probably the best form, as although less commodious it cannot be badly pitched, and is far less likely to be damaged by wind than the rectangular plan tent (or *pâl*). In the Indian army the pâl tent is used, in the English army the bell tent; the latter appears in actual use more economical, although less so in first cost. In a tropical country a tent requires to be open on all four sides by windows or doors, or it may be lifted up from the bottom. Tents for use by Europeans in tropical climates must have double roofs, or they may be pitched under trees. In Australia a tent of calico is sometimes used weighing only 40 lbs. The best material for tents is unbleached cotton; canvas is very unsuitable for use in India, as it rots very rapidly; a good cotton tent will last four times as long as a canvas one. Tent ropes should be of cotton, if of hemp they shrink when it rains and draw out the pegs; if hempen ropes be used they must not be drawn taut. If bad weather be expected the pegs should be tightened and the principal ropes re-tied. A high dry spot not far from water is the healthiest, but if working in hot weather or during the monsoons, sheltered camping ground must be found if possible; trees, banks, hills, &c., break the force of the wind. The camp should be spread, and fires and cooking tents should be kept at some distance from the principal tents. The best plan is to have one single pole double-roofed tent and one light single tent, the latter can be sent in advance, or used when transport is scarce or slow and the heavy tent cannot be brought up; the light tent may be used to sleep in, and during the morning or after the sun has gone down. It is better to camp near a village than go into the village or permit the men to stay in the village; in camp the men are more punctual and less liable to contract epidemic disease. Camp furniture should be simple; it is not required to pack very small, but must pack in a form which will resist rough usage; complicated articles should be avoided. Clothing should be packed in tin boxes.

466. If work has to be carried on for several months it is cheaper to buy bullocks and drays than hire them, but it is more troublesome. If many carts be used, and the wheels are badly made and undished, an extra pair of wheels should be carried. If the axles are of wood, spare axles should be carried. In Bengal bullocks are frequently galled badly, this is not the case in Madras; the explanation appears to be that in the latter case the yoke is not rigidly fixed to the pole, but has considerable

play in every plane; this play should always be allowed, and the yoke should be smooth, but not padded. Bullocks, horses, and other ordinary draught animals should be struck with a whip, never with a rigid stick, particularly over bony parts. An obstinate bullock which lies down may be made to rise by holding its mouth and nostrils, but such animals are worthless for draught. To try a bullock drive him with a light load in a cart with the wheels tied, if obstinate he will lie down. When roads are very bad a train of carts should be accompanied by extra men with tools. Pack bullocks do not wear a pack saddle; they have simply pads, horses should have a pack saddle, in any case the animal cannot work if part of the load is borne on the backbone. Bullocks are used in India, Australia, and the Cape of Good Hope; they are the most economical draught animals for long journeys. In a warm climate a horse should have a small saddle and saddle-cloth, no unnecessary straps, saddle-bags should be avoided, and even a revolver should be carried on the person of the rider rather than attached to the saddle. In employing lightly-built boats and canoes, the weight of the cargo should be distributed by battens, branches, or other means; a full cargo should not as a rule be permitted.

467. It is of great importance to establish a good understanding with labourers of the country through which the line passes, as without this there is great difficulty in getting labour. All men employed should be discharged quite satisfied. The officer in charge of the work should, by seeing the men paid, or paying them himself, by hearing their complaints patiently, and by putting down sharply any attempts at oppression by his subordinates, inspire confidence in himself. In general in India the people are very suspicious, easily deceived by one another, and if they are dissatisfied they go away, frequently without complaining, to spread discontent. Some races supply honester and better labourers than others; from some races, if well treated, the most liberal service may be obtained for ordinary remuneration, and this even from the common labourers; labourers often of other races seem to be exercising their intelligence either to avoid giving an equivalent for their salary, or to get advances with which to abscond. Care should be taken to find out the class which furnishes the best labourers. In most cases work has to be commenced by making advances, and risk on this account cannot be avoided when commencing work to last several months. When a large number of men are required, and they require to be paid in advance, if they are an untrustworthy class the difficulty can often be got over by paying daily

for the day's work; this plan should as a rule be adopted when villagers are required to cut jungle, the same men do not work every day, but by this means a full supply of labour may often be obtained for months when other means fail. Men employed for several months, and paid by the month, must usually be paid higher than men employed on railways and other works not requiring the men to travel; telegraph construction and repairs is also harder work. Extra work should be paid for by a present (?), an excellent effect is produced by a small extra payment. If a man is punished by fine or dismissal, it should be done in the most public manner, and the other men should be made to admit the justice of the sentence, otherwise the culprit will spread a false report. As a rule, stoppages of pay should be avoided if possible, as there is commonly a suspicion that the officer who is ready to stop pay does it for his own profit. Not only must the men be treated with justice, but it is necessary they should be made to see and acknowledge this to allay their suspicions; a little well-timed liberality is sometimes a source of great economy. If with fair treatment the men are difficult to deal with, this is probably due to some one amongst them, who should be found out and got rid of as soon as possible; firmness is absolutely essential, and the officer in charge must ensure that his authority is respected, and is the only authority acknowledged. To obtain punctuality is, as a rule, impossible, the nearest obtainable approach to it may be got, and then the clock or gong set accordingly, thus, if the men assemble half an hour late, they must be dismissed half an hour late. The most serious occurrence is the appearance of sickness in a large camp, if epidemic it causes panic, and, as a rule, it is better to leave the work and commence the construction again at another place; it is useless attempting to carry on work, for as soon as several deaths have occurred the men become frightened and abscond; it is hence better to strike camp and move at once. The following are the commonest measures to guard against disease:—Carry a supply of medicines for the principal diseases of the country, let men be attended to as soon as sick; in cold weather when engaging the men, give them each a blanket as part of their wages, to be returned if they leave within a short period; allow them time to get straw for bedding whenever obtainable, make them pitch their tents instead of sleeping under trees, never allow men to work in the morning before eating, and as soon as any disease breaks out see if it is not due to unwholesome food particularly new rice, and strictly forbid the use of such. Men who fall sick far from home cannot be neglected

on the road, and their pay cannot always be stopped; men who have worked well and are ill a day or two may be paid in full; in general pay should be reduced in case of illness, and sickly men should be dismissed as soon as practicable. Work should be carried on during the cold season only—viz., from October to March; if carried on during the hot weather or rains the cost of labour is greatly increased, as the task of each man must be reduced and sickness cannot be avoided. It is both humane and economical to confine work as much as possible to the proper season. Besides the ordinary tools in general use, a box of tools for emergencies, and for mending carts and tents, making ladders, &c., should be carried, such as an extra light tackle, rope, large files, hand saw, screw spanner, mortise chisels, measuring tape, wire gauge, &c.; these tools are issued as required, and returned to the box as soon as done with, they are therefore always ready for any emergency, and much time and inconvenience is some times saved by this means.

APPENDIX I.

LINE WIRES.

Sizes and Qualities Used; Dip; Tension; Joints, &c.

The dip of a wire is frequently stated as a fraction of the span; but as the dip varies as the square of the span, this fraction when given applies to only one particular span. The highest value this fraction can have in practice is one-third. If C be the ratio between the dip and span, Ca will be the dip, and from equation 7, page 98—

$$C = \frac{a\varpi}{8T} + \frac{1}{384}\left(\frac{a\varpi}{T}\right)^3 + \&c.$$

The first term of the series is sufficient for ordinary purposes. ϖ is the weight of a unit of length of the wire, and T is the tension at the lowest point; as these bear a fixed relation to each other for the same material and factor of safety, the quantity $\frac{\varpi}{8T}$ is a constant. If, therefore, this value be calculated for a particular wire, it will apply to wire of any size of the same material, the same factor of safety being used. No. 11 B.W.G. diameter ·12 inch, tenacity 25·9 tons per square inch = 697 lbs., factor of safety 4, weight of one yard ·1136 lb.; $\varpi = C^1 = \frac{\cdot 1136}{8 \times 174 \cdot 25} = \cdot 00008148$. For a span of 100 yards $C = \frac{100\varpi}{8T} = \cdot 008148$, the fraction the dip is of the span; and the dip $Ca = \frac{a^2\varpi}{8T} = \cdot 8148$ yard, = 2 feet 5·3 inches. It is merely necessary to multiply the constant C^1 by the square of the span to obtain the dip. If 3 be used as factor of safety, the constant C^1 is ·00005807. It should be remarked that the tension T is that at the lowest point, but the correction is readily made, when necessary, by deduction from the tension. Under ordinary circumstances this is not necessary—*e.g.*, in the example marked out above, the error in tension is ·09 lb. only. If the constant C and the span a be known, the corresponding tension T may be calculated. It is stated that the tension on the wires in England is one-third their tenacity, and the dip allowed is 24 inches in 100 yards span at 60° F.; this is said to be (Preece and Sievewright) "the standard by which all wires are regu-

lated." Applying the formula, the tenacity stated by the authors for No. 11 wire being 650 lbs., $\cdot 00006 = \frac{\cdot 1136}{8T}$ $\therefore T = 213$ lbs., or $3\frac{2}{3}$ lbs. less than one-third the ultimate tenacity. This tension is excessive. Other authors (Messrs. Clark and Sabine) state the dip to be 1·5 foot in 240 feet span, in mild weather; the factor of safety in this case is about 4. In Australia the dip specified is not less than 14, nor more than 20 inches, in a span of 88 yards. $\cdot 00005807 \times 88^2 = 16\cdot 177$ inches, hence the mean dip specified corresponds to about 3 as factor of safety. In neither of the cases in which the factor of safety is so low as 3 is the tension actually measured, and it is probable a higher factor is actually used in practice. In India the lowest factor employed is 4. On the continent of Europe 4 is the lowest factor admitted, but a higher is generally used. In Italy and Switzerland the dip allowed is 1 per cent. of the span, the spans being 70 metres (229·6 feet) and 60 metres (196·8 feet) respectively. In both cases the factor of safety is above 6. In the second case the specified tenacity is about 25 tons per square inch, hence the factor of safety is 7. On the Italian lines rather less dip is allowed to thin wire. In Belgium the factor prescribed is at least 6; but in no case is it to fall to less than 4, even by accident, when this possibility is foreseen. On the French railway telegraphs the tension is not permitted to exceed 6 kilometres per square millimetre; the factor of safety is about 6·5. In this case the tension is actually measured with a dynamometer. A considerable dip is inconvenient when the wires are numerous, because it renders greater care necessary to prevent contacts. The only advantages of a slight dip on a line of few wires are, the additional height, and the improved appearance. The disadvantage is very great, and consists in the additional stress imposed on the wire, insulators, and poles.

Wire is generally galvanised, but in some cases plain wire is used. In Austria plain wire is used exclusively; it is preferred because it is cheaper and stronger. The difference in price is 30 per cent., or more. The relative weakness of the galvanised wire is probably exceptional in the case of the Austrian wire, as the tenacity specified for the plain wire is exceptionally high. In Holland galvanised wire is generally used, but plain wire is employed for long spans, because it is stronger. In Belgium the Nos. 8 and 11 are galvanised, No. 6 is used plain.

All administrations do not use the same high quality of wire, nor does each insist on the same extreme softness. Probably the tenacity specified by the East India Government Telegraph Department is as high as attainable in soft wire (25·9 tons per square inch). The Belgian specification requires 25·4 tons, the Italian 24·76 tons, the Dutch 30·285 tons; Blavier states 25 tons. The Swiss specification requires about 25 tons; for 4 millimetre wire it is 25·38, and for 3 millimetre and 5 millimetre 3 and 2 per cent less respectively. The Austrian specification requires 39·4 tons. The last specification requires the wire to be annealed and supple; the high tenacity renders it probable the material is homogeneous metal.

The smallest size used for line wires in Europe is 3 millimetres diameter, or approximately No. 11 B.W.G.; this is used for short lines, &c. In Austria this size is used when the soil is bad, or the wires numerous; and it is used for short lines in Belgium, Norway, Switzerland, and England. No. 9 is the standard size in America; No. 8 is used, but much less generally; and No. 6 is used exceptionally, as over the Sierra Nevada mountains, and through some wooded country on the Pacific Coast. In Norway No. 8 is the only wire used for new lines, while in England it is used for all short circuits of minor importance. No. 8 B.W.G. is largely employed in Europe, being used in Austria, Germany, Belgium, Norway,

Holland, Switzerland, Turkey, England, &c. No. 6 B.W.G. is used in Europe for long circuits, particularly on international lines, and is the largest wire used generally. Some No. 4 is used in Turkey; and although No. 8 is the size adopted generally in England for all through circuits, No. 4 is employed for very long circuits, or under other exceptional circumstances. In Australia Nos. 8 and 10 are used for short circuits, and No. 6 for circuits from 300 to 500 miles.

The distances between wires on the same pole differ. In Belgium the distance is 0·5 metre (23·6 inches), reduced to 0·5 metre (19·7 inches), or 0·4 metre (15·75 inches) over paths or roads. In Denmark the insulators on the same side of the pole are 40 centimetres (15·75 inches) apart. In France normally 0·5 metre (19·7 inches) for 4 millimetre (No. 8) wire, the distance being actually measured. In India the practice of placing the insulators in pairs on the same level is being discontinued, and the arrangement shewn in Fig. 79 is being adopted; the vertical distance between alternate insulators (Fig. 79) is 6 inches. In England the vertical distance is 12 inches, the horizontal 16 inches. In Norway insulator arms alternate, so that wires are 30 centimetres (11·8 inches) apart vertically, and 60 centimetres (23·6 inches) on the same side of the pole. In Holland the minimum distance is 30 centimetres (11·8 inches). In Switzerland the vertical distance on the same side of the pole is 45 centimetres (17·7 inches) to 1 metre (39·4 inches).

In Italy care is taken to make the joints near the poles, for facility of inspection, and to prevent contacts. In England joints are kept within 12 feet of the pole (Preece and Sievewright), to prevent the joint hooks catching the other wires. These precautions are troublesome to take, and not necessary, if the joints be well made and long hooks be not left projecting. On the North-Western Company's line (U.S.) the joints are not generally soldered; but in cities where the wires are liable to corrosion by sulphurous acid from coal smoke, the joints are examined and soldered when they begin to shew abnormal resistance. In Europe joints are soldered, the practice of omitting the soldering having been tried in some instances and given up. The Britannia and the twisted joints are generally used, the former for thick, the latter for thin wire. In Belgium, when the twisted joint is used in ungalvanised wire, it is not only soldered, but a thin copper wire is twisted two or three times round the joint, and soldered to the line wire on each side; this ensures metallic contact, even if the solder of the joint cracks. The following different joints have been or are used. In the Bavarian joint the wires are twisted together for 3 inches, the free ends bound, bent at right angles, and cut off. On the Indian lines tubes were used in which the strength of the joint depended on the solder, and electrically bad joints would be mechanically bad also; the joint did not answer, and its use was abandoned. On the French and Swiss lines the thick wires are joined by tubes instead of by binding wire; but the thin wire on the Swiss lines is joined by the ends of the wire being put through holes in a small brass cylinder, and fixed by a steel-pointed screw, screwed in between the wires, and at right angles to them. A joint on a similar principle is used for American compound wire; the ends of the wires are placed in a tube of suitable shape, a rivet is driven between them to bend them in the tube, and solder is then used to ensure contact. With this joint, or any soft-soldered joint, the American compound wire is said to become granular in texture, and ultimately to break. Mr. C. H. Haskins, North-Western Company, U.S.A., uses what he calls a spring joint in compound wire. In this joint the two wires are twisted each six or eight times round the other, the free end of each wire is then brought back and twisted round its own

wire, when the stress is put on the several coils close somewhat together. This joint transmits vibrations better than a shorter and more rigid one, and hence is stronger. Mr. Haskins joins an iron and a compound wire together at river crossings by a joint on a similar principle; the compound wire is first twisted round the iron wire, the iron wire is then bent into an eye enclosing the first joint, and is twisted round itself and the end cut off, the free end of the compound wire is then again twisted round the iron wire outside the eye on the latter. The idea involved in the spring joint is the same as in the splice devised by Sir W. Thomson for his wire-sounding line. The joint generally used weakens the line: a more flexible joint would be a great improvement, particularly in long spans. Compound wire has not been favourably reported on in England; it has been tried in India with unsatisfactory results, but is still under trial in both countries. The idea of making a wire having a greater conductivity and tenacity with less weight, as compared with iron wire, is an excellent one; but the compound wire will not bear bending; if bent it has been found to rust in consequence of its heterogeneity. Compound wire is used by the North-Western Company (U.S.A.) for river crossings; but in Europe and in India, iron, homogeneous metal, and steel, are used. The modulus of tenacity of steel wire supplied to the Indian Government Telegraph Department is as high as 11½ miles.

The use of platinum faced discs and screws (p. 343) has been discontinued in India. They were found liable to get dirty and be left loose or open. A thin wire is now used to bridge over the solution of continuity at testing insulators, testing balls, &c.; this wire is soldered to the line wire, and if the lines are to be disconnected, the wire is cut and afterwards resoldered. It was also found that copper wire, used for the above purpose, got brittle in time, and was then liable to rupture; only iron wire is now employed.

It is stated (Preece and Sievewright) that for very long spans a wire varying in diameter is employed, the smallest section being placed in the centre of the span. This, although theoretically correct, would be troublesome in practice; and although it may be done in England, it is seldom if ever applied elsewhere. The longest spans likely to be required may be made of steel wire (the modulus of tenacity of which may exceed 11 miles), with great practical advantage, particularly in the case of repairing the span, if thrown down, and part or all of the wire lost. The gain by varying the diameter of the wire would be greatest when not only the span, but the dip also, is a maximum; in such extreme cases there is no difficulty in obtaining wire of sufficient tenacity, the difficulty is to insulate the wire.

APPENDIX II.

WIRE GAUGES (pp. 234, 296).

The following table exhibits the relation between the Indian and Birmingham gauges. The former applies to iron wire only, the latter, being based on the diameter, applies to all wires. The table is calculated on the following data:—A rod 1 inch diameter and 1 mile long weighs 13,833·6 lbs., *i.e.*, a cubic foot weighs about 481·3 lbs. The modulus of tenacity is taken as about 3⅜ miles, equal to 25·9 tons on the square inch.

Gauge. No.	Weight in lbs. per Mile.	Yard.	Foot.	Diameter in $\frac{1}{1000}$ Inches.	Area of Section in $\frac{1}{10,000}$ Sq. Inches.	Breaking Strain in Lbs.	B. W. G. (approximate.)
1	25	.0142	.0047	42	14	83	19
2	50	.0284	.0095	60	28	167	17
3	75	.0426	.0142	75	43	250	15
4	100	.0568	.0149	85	57	333	14
5	125	.0710	.0237	95	71	417	13
6	150	.0852	.0284	104	85	500	...
7	175	.0994	.0331	112	99	583	12
8	200	.1136	.0379	120	114	697	11
9	225	.1278	.0426	127	128	750	...
10	250	.1420	.0473	134	142	833	...
11	275	.1562	.0521	140	156	917	10
12	300	.1705	.0568	147	170	1000	...
13	325	.1847	.0616	153	184	1083	9
14	350	.1989	.0663	159	198	1167	...
15	375	.2131	.0710	166	213	1250	...
16	400	.2273	.0758	170	227	1333	8
17	425	.2415	.0805	175	241	1417	...
18	450	.2557	.0852	180	255	1500	...
19	475	.2699	.0900	185	270	1583	7
20	500	.2841	.0947	190	284	1667	...
21	525	.2983	.0994	195	298	1750	...
22	550	.3125	.1042	200	312	1833	6
23	575	.3267	.1089	204	326	1917	...
24	600	.3409	.1136	208	341	2000	...
25	625	.3551	.1184	212	355	2083	...
26	650	.3693	.1231	217	369	2167	...
27	675	.3835	.1278	221	383	2250	5
28	700	.3977	.1326	225	397	2333	...
29	725	.4119	.1373	229	412	2417	...
30	750	.4261	.1420	233	426	2500	...
31	775	.4403	.1468	237	440	2583	...
32	800	.4545	.1515	240	454	2667	4
33	825	.4687	.1562	244	468	2750	...
34	850	.4830	.1610	248	483	2833	...
35	875	.4972	.1657	251	497	2917	...
36	900	.5114	.1704	255	511	3000	...
37	925	.5256	.1752	258	525	3083	...
38	950	.5398	.1799	262	539	3167	3
39	975	.5540	.1846	265	554	3256	...
40	1000	.5682	.1894	269	568	3333	...
41	1025	.5824	.1941	272	582	3417	...
42	1050	.5966	.1989	275	596	3500	...
43	1075	.6108	.2036	279	610	3583	2
44	1100	.6252	.2083	282	624	3667	...
45	1125	.6394	.2131	285	639	3750	...
46	1150	.6536	.2178	289	653	3833	...
47	1175	.6678	.2225	291	667	3917	...
48	1200	.6820	.2273	294	681	4000	...
49	1225	.6962	.2320	297	695	4083	...
50	1250	.7104	.2367	300	710	4167	1

In the preceding article (Appendix I.) the approximate numbers of the Birmingham gauge were given for convenience; but on the continent of Europe there is a general objection to the use of any arbitrary gauge, and the diameter of the wire is stated in millimetres. The sizes used for line wires and their approximate numbers on the Birmingham gauge are as follows:—

Diameter in Millimetres.	Diameter in Inch.	Number B.W.G. Approximate.
5	0·197	6*
4·5	0·177	7
4	0·157	8*
3·5	0·138	10
3	0·118	11*

Four millimetre wire is considered the standard wire. In France reduced circuits and insulation resistances are stated in terms of the resistance of 1 kilometre of this wire. In India 1 mile of No. 1 B.W.G., or No. 50 Indian gauge is the unit used for expressing the length of reduced circuits. The reduced circuit so expressed is termed the "modulus" of the line wire. This term *modulus* in this sense appears inferior to the older term, *reduced circuit.*

The Indian gauge proceeds by smaller differences than the Birmingham gauge, particularly in the larger sizes. So many different sizes are not required, but in practice the sizes used weigh 900, 750, 600, 300, 150, and 75 lbs. per mile, all these numbers being multiples of 75.

The practical advantages of the Indian gauge will be seen from the following formulæ, n being the number of the wire:—

I. Weight per mile, ... $=25n$ lbs.

II. Diameter, ... $=\dfrac{\sqrt{n}}{23\cdot5}$ inches nearly.

III. Sectional area, ... $=\dfrac{n}{704\cdot5}$ square inches nearly.

IV. Tenacity, ... $=\dfrac{1000}{12}n$ lbs.

V. Working load, factor of safety 4, . $=21n$ lbs. nearly.

VI. Stress on an Angle insulator, φ being the supplement of the angle contained by the wire, the stress on the wire being its full working load, . . $\left\{ \begin{array}{l} =42n \sin\dfrac{\varphi}{2} \text{ lbs., or} \\ =21n\sqrt{2(1-\cos\varphi)}. \end{array} \right.$

VII. 1 ton measures . . . . $\dfrac{89\cdot6}{n}$ miles,

Or, allowing for waste, &c., pays out . . . . $\dfrac{85}{n}$ miles.

1 cwt. measures . . . . $\dfrac{4\cdot48}{n}$ miles.

Or, allowing for waste, &c., pays out . . . . $\dfrac{4\cdot25}{n}$ miles.

The electrical conductivity of a wire varying directly as its weight per unit of length, the calculation of a reduced circuit is much simpler with the Indian gauge than with the Birmingham gauge. The Indian gauge table and formulæ are abstracted from official instructions issued to the Indian Department.

* These sizes are used very generally

APPENDIX III.

LINE INSULATORS (p. 339).

Glass is the material generally used for insulators in America. It is much cheaper than porcelain, and being homogeneous abrasion of its surface does not expose a porous interior. The highest quality of porcelain used for insulators, as compared with glass, has not the great superiority in strength a less vitrified porcelain would have; it is much dearer than glass; it is vitrified throughout, and any degree of vitrifaction may be attained by varying the ingredients; but a high degree increases the cost, as the highly vitrified material softens in the kiln, and many insulators are spoiled by distortion. The deposition of moisture is probably as great on highly vitrified porcelain as on glass, and evidently the higher the degree of vitrifaction the nearer the porcelain approaches glass in its mechanical properties. Toughened glass, the recent invention of M. Bastie, appears to be a material likely to prove of the greatest value for insulators. It appears probable insulators of toughened glass would be stronger and cheaper than those of fine porcelain, and as the glass could be used thinner than porcelain it might be worked into shapes deeper, narrower, and having more cups, than the patterns now made of porcelain. The form of the American glass insulator is a single bell, somewhat flat in shape and thick; the total length of the glass outside is about 3·75 inches, width of bell at lower edge about three-fourths of length, inside depth of cup about one-fourth of length, and the wire groove is about two-thirds down the insulator, so that the leverage on the stalk is as small as possible. The stalks or pins are of wood, commonly oak, seasoned and painted, or dipped in melted paraffin until they take a smooth coat. These pins are screwed into the glass bell. The depth of the female screw in the cup is equal to about half the height of the glass. The stalk is not cylindrical but conical, its enlargement downwards partially closing the wide mouth of the shallow bell, and considerably improving the insulation in a damp atmosphere. The coating of paraffin on the stalk gives 3 inches additional insulating surface superior to glass in a moist atmosphere. The advantage of lowering the point of attachment of the line wire on the stalk is gained in the French pattern, which is very similar to the American in shape, but the expansion of the stalk renders the American pattern superior in damp weather. The American insulators are stated (D. Brooks) to be fragile, and sometimes a large percentage is broken in erecting the wire; but they are used very generally, and appear to give satisfaction. The American "screw glass" insulator is attached to the pole by insertion of the stalk into a hole in the top of the pole or in the cross-arm, or the stalk is made large, and the insulator is spiked to the pole directly by the stalk, the latter being placed at such an angle with the pole that the cup and pole are not in contact. When the stalk is inserted in a hole in the pole, it has a collar or flange turned on it to prevent it sinking too low as the pole decays. In Europe glass insulators are used on some lines; they are of single bell patterns only. They are used in Switzerland, and are similar in shape to the American, but are not so strong. They are only used for thin wire, No. 11 (·118 inch diameter), and on lines seldom exceeding 100 kilometres in length. The stalks are of iron, and are cemented in with gypsum. In Australia porcelain insulators are used; they are fitted with wooden stalks, excepting at angles and terminals, where the great stress renders the employment of iron necessary. The use of iron

about insulators is avoided as far as practicable; when the stalk of an insulator is of iron a piece of a material termed "leather cloth" is placed between the iron and porcelain. The wooden stalks used on the Australian lines are similar in shape to those used on the American lines; they are conical, and have a flange about $1\frac{3}{4}$ inch radius from the longitudinal axis; they are made of a wood locally known as "black wood." The wood is seasoned, and the turned stalks are boiled for one hour in a mixture of equal parts Venice turpentine, shellac, and resin, to every 3 gallons of which a quart of melted paraffin has been added. This preparation improves the insulation and increases the durability of the stalks. The very general preference in America and Australia for wooden stalks proves they may be used with advantage, and the mechanical advantage is obvious when the stress on the insulator is not so great as to render the employment of iron or steel necessary. With thin wires, *i.e.* not thicker than No. 8 B.W.G., the use of wooden stalks is, as a rule, practicable. The climates of the United States and Australia are favourable to telegraphy—wooden pins would require more frequent renewal in damp tropical climates. In America and Australia wooden poles are used, and the insulator stalks are more durable than the poles; with iron poles the insulator pins would have to be periodically inspected, or changed after a few years exposure.

On the lines of the North-Western Company (U.S.) the Kenosha insulator is used. This insulator is in form a narrow cylinder, it is made of wood covered with a patent, so called indestructible, insulating coating; the turned cylinders are kiln-dried, then dipped in the compound, and again baked; the compound sinks into the wood, a second coating of compound is applied, and gives a glazed surface. These insulators are employed in several ways: as supporting insulators they have wooden stalks, shaped like those of the "screw-glass" insulators, and screwed in; when only a few are attached to a pole they are fixed by the stalk as the glass insulator; when cross-arms are used the stalks are inserted in the upper surface of the arms; as suspending insulators they are let into the under surface of the cross-arm, and fixed by pins put into the cross-arm at right angles to the insulator and fitting into a groove in the insulator.

Ebonite is sometimes used for insulators; these insulators are generally much smaller than those of porcelain, but do not differ from them in shape. Ebonite does not bear exposure well, and its use for insulators may be regarded as exceptional. Even for small military insulators porcelain is commonly preferred, but for these lines ebonite has the great advantage of less liability to injury in transit, and as the lines are not permanent the insulators may be varnished before use, and the liability to deterioration of their surface is of far less consequence than on permanent lines. Ebonite insulators are used on some short lines in Australia, and in a few cases in Europe, where porcelain or glass would be liable to injury from missiles; but the iron hood is more generally relied on as a protection in such cases.

The Brooks insulator is used on some lines in America; this insulator is composed of an iron cylindrical hood, commonly 6 inches long and 1 inch in diameter, of a blown glass bottle, which is cemented into the hood, mouth downwards, to form the inner bell, and inside this bottle is cemented the iron stalk by which the wire is held suspended. The cement is said to be composed principally of sulphur and sand. After the parts have been put together the insulator is saturated with paraffin. This insulator is said to give very satisfactory results at first, and to maintain its efficiency if painted yearly with paraffin—an operation which may be performed without removing the insulator from the pole. M. Gaugain compared this insulator with an ordinary porcelain insulator; the resistances were—

	June 18, 1874.	October 9, 1874.	May 28, 1875.
Brooks, . .	2,269	39	26
Porcelain, .	327	83	22

The unit is one million kilometres of 4 millimetres iron wire. The Brooks insulator deteriorated more rapidly, but after about eight months exposure it was as good or better than the porcelain one. The peculiarities of this insulator are its narrowness, the contraction of the glass round the stalk or pin, and the nearness of the edges of the hood to the line wire; the hood being close to the wire, and having two curved indentations in its edge to avoid actual contact between the line wire and the edge of the hood. This insulator is fixed to the pole by a bent rod with a thread to be screwed into the side of a wooden pole, by a bracket and saddle to be bolted round an iron pole, or by the hood being inserted a short distance into the under side of a wooden cross-arm. In common with other hooded insulators this pattern is not readily broken by missiles. The narrow shape of this insulator is highly favourable to retention of high resistance in a humid atmosphere or during rain. The objections to this form are—the difficulty of removing spiders' webs and the nests of ants, mason wasps, and other insects, and the fact that when once dirty rain cannot wash them clean nor wind blow out the dust. The former objection would no doubt prove a serious one in a tropical climate, the second is common in a greater or less degree to all hooded insulators, for in proportion as an insulator is wetted and washed clean by rain, it loses its essential property during rain or in a moist atmosphere.

In the Brooks insulator, and in another cylindrical pattern, termed the "Winkle" form, the wire is suspended from a twin hook at the end of the stalk; when the wire is put on this hook it is so bent that it cannot run; binding is thus rendered unnecessary. The French government pattern insulator has a cylindrical head and rather open bell; it is claimed for this form that the groove for binding the wire in being lower down on the bolt or stalk than in most other patterns of supporting insulators, the leverage with which the tension of the line acts on the insulator and bracket is reduced; but this can only be gained by making the bell short and open, a form not suited to damp localities. When wooden stalks are used, an expansion of the stalk, by partially closing the mouth of the bell, removes, in a great measure, this objection, but wooden stalks are not used in Europe. In India it has been observed when line wires were put on a top groove of a porcelain insulator, the wire and porcelain were both chafed by the motion of the wire; hence the line is now always bound to the groove round the insulator, even in those insulators which have a top groove. This does not apply to iron-hooded insulators.

Sometimes the conditions are such that the ordinary pattern insulators cannot be employed, and the insulators have to be chosen or designed to meet the peculiar conditions presented. On the sea coast, and in all situations where the air is highly charged with moisture, or moisture and salt, the ordinary bell insulators insulate very imperfectly. The Brooks insulator is said to insulate well under these conditions if attended to; but no means of securing permanent good insulation, under such circumstances, has been devised. The Italian government experienced great difficulty in insulating coast lines, and experimented on several measures, including reduction of the number of supports; the Indian government experienced much difficulty on one section of line. The insulators for such lines should be deep, cylindrical, and narrow, wide open bells being avoided; and these insulators should be removed periodically, and carefully washed. The supports to the

line should be as few as consistent with safety, and as the wire is liable to corrosion it should not be thin. Thick wire in such cases has electrical advantages, the insulation being unavoidably low.

For terminal insulators a large strong pattern is used, but in some cases the strongest terminal insulator ordinarily made would not be strong enough. The span across the River Kistna, in the Madras Presidency, is 5,070 feet, the wire is a seven strand rope; to insulate this wire it is passed round a grooved marble ball at each end; these balls are fastened to the poles by iron straps, and the poles (being short) are each enclosed in a wooden casing, through slits in which the wire rope passes. This plan has proved successful. The large number of cables used in Norway led to the employment of a special insulator at the junctions of the cables and land lines. These insulators are double bell, but the stalk and bell are in one piece, and of porcelain. The stalk is a tube, the cable is brought up underneath the bracket, and the core is inserted in the tube, the conductor projecting above the insulator; the hollow stem of the insulator is then filled with a melted mixture of wax and resin, and a small plug of porcelain with a hole in its centre is threaded on the exposed conductor and pressed down on to the melted mixture. The conductor projecting from the top of the junction insulator is joined to the land line, suspended higher on the pole. This mode of joining a cable and land line is cheap, and is said to be effectual; in a tropical climate the mixture would run out of the tubular stalk—a less fusible material would be necessary. Another special pattern insulator is used to protect the Norwegian lines from lightning. It is manifest without some provision of this kind the numerous cables would be very liable to injury. This insulator is an open double bell of ebonite, but its stalk consists of two concentric brass tubes, both closed, but not communicating with each other; the interval between them is 1 millimetre. The inner tube is insulated from the outer, and it is fastened to the insulator by a small bolt passing through the porcelain, and on which is a nut screwed down on to the summit of the bell. The wire passes over this nut, and a second nut is screwed down on it. The outer tube is connected with the earth; it is hermetically sealed, and the space between the two tubes is a partial vacuum.

Insulator stalks and arms are in some cases varnished with a resinous compound, to which a little fat or paraffin is added to make it less brittle. This is not open to the objections that apply to an ebonite coating; containing no sulphur the iron is not attacked, and the varnish does not readily peel off. On the North-Western Company's lines (U.S.) the cross-arms are of clear pine, and they are treated with Kenosha insulator compound in the same manner as the insulators.

Insulators having the two cups burnt separately, and then cemented together, are used in England and Belgium; their supposed advantages are—1st, The improbability of *both* cups being cracked by an accident which might crack one, and of two faulty cups being put into the insulator; 2nd, (Preece and Sievewright) the two cups can be better burnt separately than if made together. But an insulator with the cups in one piece is stronger than one with separate cups; no difficulty should be experienced in burning so small a mass as an insulator, and testing should be relied on to detect defects in the porcelain. The more general preference for the two bells in one piece appears to be amply justified.

In Norway, Denmark, Switzerland, and Italy, the use of cements for fixing insulator stalks in the porcelain cups is avoided. The stalks are fixed by screwing them in with a covering of tarred yarn. This has been found to answer, and to greatly reduce breakage. In India the yarn shrank, the

stalks became loose, and many cups were broken in consequence. The cups were less durable than when fixed with a rigid cement. To fix insulator stalks with yarn, a plug of tow should be first placed in the bottom of the hole, the yarn should be slightly untwisted as it is wound on the stalk, it should be wound on as tightly as possible, and, lastly, the stalk should be screwed into the porcelain. A good insulator cement is said to be made by mixing ten parts of good freshly-burnt gypsum with one part of fine iron filings. A commonly used cement is pure gypsum.

The stalks of insulators are commonly made slightly taper at the end fixed in the porcelain; this causes the stalk to act as a wedge in a supporting insulator, and to draw out more readily from a suspending insulator if it becomes loose. In some recent patterns the iron stalks are enlarged into a ball at the end inserted into the porcelain. When curved pins or brackets are used with insulators, particularly when in the form of bent rods to be screwed into the pole, the point of attachment of the line wire should be on the same level as the attachment of the bolt or bracket to the pole. This prevents torsion at the fastening, which, in the case of an arm screwed into the pole, might turn the arm.

APPENDIX IV.

POLES.

Dimensions, Spacing, Erection, &c.

Wooden Poles.—On the American lines more poles are used to the mile than on European and Asiatic lines; Mr. D. Brooks states 30 to 40 are used, presumably when the wires are numerous, or there is liability to damage from sleet and snow. Over the Alleghanies as many as 60 poles per mile are used to prevent accident from sleet, but the wire has been broken when too tight. The telegraph system of the Pacific coast has 15,000 miles of wire, of which 10,000 belongs to the Western Union Co., 4,000 to the Pacific Railroad Co., and 1,000 miles to other companies. The poles used are as follows:—Throughout California, and on the great overland route, for single wire lines, sawed redwood poles, 8 by 8 inches at base, 4 by 5 inches at top, and 22 feet long, set 4 feet in the ground, and from 20 to 25 per mile according to the nature of the country; for two to six wires the poles have the same transverse dimensions, but are 25 feet long, and used 25 to the mile. This redwood closely resembles cedar, is soft and brittle, but more durable in the ground than other American woods. On lines which have stood 15 and 20 years very few poles have rotted. Mr. Geo. Ladd states he has seen some foundation timbers of this wood which have stood 75 years. The botanical name of this tree has not been supplied. In Northern California, Oregon, Washington, and British Columbia, round cedar poles are used. These are stripped of the bark, and, when time will permit, seasoned. The butts are charred. They are 22 to 25 feet long, with a minimum diameter of 9 inches at base and 5 inches at top. These poles are inferior in durability to those of redwood, partly, no doubt, because the latter are of sawn timber. After standing four or five years, cedar poles are either reset or strengthened in the following manner:—A hole is made in the ground at one side of the pole, a stout sound piece of timber is firmly

planted against the pole, and standing several feet above ground; two servings, each of three turns, of No. 9 galvanised wire are passed round the pole and timber, one 1 foot above ground, the other near the top of the strengthening timber. This is cheaper than replanting the poles, and is very reliable; 200 miles done ten years ago is still good. This mode of strengthening wooden poles decayed at the ground line has been applied by the author to large wooden masts. It is an economical method of strengthening wooden poles containing much sapwood, when this has rotted at the ground line and left the pole weak. Strengthening with a piece of sound heartwood timber may in such cases prolong the life of the pole longer than replanting. The North-Western Company (U.S.A.) use white cedar exclusively for poles. As the number of wires is constantly increasing, a greater number of poles is used than would otherwise be employed. The smallest poles are 25 feet long, and 5 inches diameter at the small end. They are barked, planted 4½ to 5 feet deep according to the soil, and 25 to 30 to the mile.

Wooden poles are ordinarily used in Australia, but on some of the principal railway lines iron poles (Oppenheimer pattern) are employed. The best of the woods used are red gum, blue gum, boxwood, and iron bark, all varieties of the Eucalyptus family. Red and blue gum poles have been found serviceable after standing 17 years, and boxwood after nearly as long. The durability depends in a great measure on the season at which cut, and nature of the soil in which planted. The average durability of ordinary poles in Victoria is about nine years. These poles are saplings, and no preservative preparation is used, labour being very expensive. The poles are simply barked, and the butt thoroughly charred over a length of 5 feet 6 inches. The dimensions are, 25 feet long, 30 to 36 inches circumference at ground line, and at least 18 inches at top; 30 to 35 feet long, 36 to 42 inches at ground line, and 18 inches at top. When saplings cannot be obtained squared timber is used. The dimensions are 25 feet long, 8 inches square at ground line, and 6 inches at top; angle and terminal poles 12 inches diameter at ground, 7 inches at top. In the streets of towns and villages the poles are dressed with a plane, and the upper part painted with three coats of white lead and oil paint to within 6 feet of the ground; the remaining portion is painted black. As the insulator is inserted in the top of the pole, a galvanised iron band, at least 1 inch wide, is fixed round the end of the pole 1 inch from the extremity, the ends of the strap overlap 2 inches, and the fastening is five 2-inch galvanised iron nails; a hole, at least 5 inches deep, is bored for the insulator pin. The poles are planted 20 to the mile, and 5 feet deep. In rock the depth is reduced to 4 feet. The headway allowed is 18 feet over land and 25 over water.

On some European lines the poles are placed a fixed distance apart, irrespective of the number of wires carried, higher and thicker poles being used for carrying more numerous wires. This is the case on the French, Italian, Belgian, Norwegian, and Swiss lines. On French railway lines the standard distance is 70 metres (230 feet); this distance is maintained on all lines and on curves exceeding 400 metres (438 yards) radius. On curves 400 to 1,000 metres (430 to 1,094 yards) radius every support is of two poles coupled together, when the radius is 1,000 to 2,000 metres (1,094 to 2,187 yards) coupled poles are used alternately with single ones, the single ones being placed in the alignment between the coupled poles. When the radius exceeds 2,000 metres (2,187 yards) single poles, selected for strength, are used, but one in three may be coupled. When the radius of the curve is less than 400 metres (438 yards), then the distance between the poles is reduced below 70 metres (230 feet). In Italy, Belgium, Norway, Switzer-

land, and some parts of Germany, the normal spacing generally adhered to on straight lines is as follows:—Italy, 70 metres (230 feet); Belgium, 100 metres, reduced lately to 90 metres (295·3 feet); Norway, 50 metres (164 feet); Switzerland, 60 metres (196·8 feet). On the Italian coast lines the minimum distance is 90 metres (295·3 feet), it being desirable to reduce the number of supports to improve insulation. On the Norwegian lines exposed to storms and snow, the spacing is reduced to 35 metres (114·8 feet), and even less. In most of the instances given, the normal distance taken is so short as to render it unnecessary to increase the number of supports as the number of wires is increased; but on curves the poles are placed nearer together, the distance being regulated by the radius of curvature—*e.g.*, on the Bavarian lines the distances adopted were,—on straight lines and curves exceeding 3,000 feet radius, 150 feet; curves of radius 1,500 to 3,000 feet, 125 feet; 1,000 to 1,500 feet, 100 feet. On the Belgian lines the minimum distance is 50 metres (164 feet). On curves, of course, in any case the standard spacing may be departed from to give additional security or headway. On the Austrian lines the spacing varies between 35 metres (115 feet) and 50 metres (164 feet). On the Danish lines the maximum on road lines is 200 metres (328 feet); on railway lines 65 metres (213 feet) to 80 metres (262 feet). On the Dutch, Indian, English, and some other lines, the spacing varies with the number of wires: the maximum distance in Holland is 75 metres (264 feet); in India 110 yards; in England, for minor road lines and branch railway lines, the maximum distance is 293 feet, on trunk lines 220 feet.

The sizes of the poles generally used differ in different countries. In every case longer or shorter poles are used for exceptional conditions. The sizes used in America and Australia have been stated above; those used in France, India, &c., in the body of the work. In England 22 feet is the minimum length, excepting on one wire extensions, when 20 feet is admitted; on railways 20 feet is the length used, 18 and 16 feet having been used occasionally. One foot extra is allowed for every two wires after the first; 12 feet clear is the minimum ordinary headway, and 20 feet is the minimum at road and railway crossings. Round poles are used, except for terminals and sharp angles, for which squared timber is used. For round timber the minimum diameter at small end is 5 inches for minor lines, and 6 inches for trunk lines; the squared timber is of a section according to requirements.

The dimensions of poles used by several European administrations are as follows—the transverse dimensions are specified minima:—Austria, 20 to 25 feet long, least diameter 12 to 15 centimetres (4·72 inches to 5·9 inches). Bavaria, 25 to 31 feet long, least diameter 12 centimetres (4·72 inches). Belgium, common sizes, 6·50 metres, 7·50 metres, and 9 metres (21·3 feet, 24·6 feet, and 29·7 feet); but larger poles are used up to 20 metres (67·6 feet). Denmark, average, 8·16 metres (26·5 feet). French railway lines, 8 metres to 10 metres (26·24 feet to 32·8 feet). Italy, ordinary poles, 6 metres and 8 metres (19·68 feet and 26·24 feet) long, least circumference 30 centimetres (11·8 inches), and circumference measured at 2 metres from thick end 50 centimetres (19·7 inches). Special poles, 9 metres and 10 metres (29·5 feet and 32·8 feet) long, and each 36 centimetres and 56 centimetres (14 inches and 22 inches) in circumference, measured as above. Larger poles than these are 6 centimetres additional in circumference. Norway, 7 metres to 8 metres (23 feet to 26·25 feet) long, 0·5 metre (19·7 inches) circumference at small end, and 0·66 to 0·82 metre (21·6 inches to 32·3 inches) at the thick end. Holland, 6 metres to 9 metres (19·6 feet to 29·5 feet) long, 21 centimetres (8·27 inches) diameter; 9 metres to 11 metres long, 24 centimetres (9·4 inches) diameter. The diameter is measured in each case 1 metre from the

thick end. The minimum diameter at the thin end is in all cases 125 millimetres (4·9 inches). 6-metre to 7-metre poles are generally used. Switzerland, length 8 metres, 9 metres, and 10 metres (26·24 feet, 29·5 feet, and 32·8 feet), diameter at small end 12 centimetres (4·72 inches), and at thick end 18 centimetres, 20 centimetres, and 25 centimetres (7·08 inches, 7·98 inches, and 9·85 inches) respectively.

The above particulars relate to wooden poles only. The wood generally employed is pine wood, excepting on some Italian and a few Swiss lines, on which wild chestnut is used. The latter wood is soft, but strong and durable in the ground; its ultimate durability is not settled; it has lasted more than sixteen years in Switzerland, and is estimated to last twenty years without renewal. In Italy it has not been in use so long, but will prove equally durable; it is used on coast lines exposed to storms, and with a minimum spacing of 90 metres, the pine wood having failed. It is felled between November and March, barked and seasoned before use. Slight curves are admitted in the poles, and only sound wood is used. The durability of pine wood poles is variously estimated as follows:—England, average for unprepared round poles seven years. Boucherising is generally considered uncertain, creosoting is considered the best, but it may fail from want of care, &c.; Norway, in five to seven years unprepared poles are mostly replaced; Boucherised require slight renewals after ten years; Switzerland, seasoned larch has been found good after eight or ten years; Bavaria, injected timber lasts on an average only seven years; injected wood is very commonly employed; Boucherised and creosoted most generally, and with satisfactory results.

The following partial and supplementary measures are taken to increase the durability of poles:—The Italian chestnut poles are charred for 1·50 metre (4·9 feet) to ½ centimetre (·2 inch) deep. In Norway the Boucherised poles are tarred 2 feet above and below the ground line to prevent the salt being washed out by rain and humidity; this is applied at once to seasoned wood, but one or two years later to unseasoned wood. Tar and iron pole roofs are commonly employed, but the end is attained cheaper in many cases by other means—*e.g.*, in Austria the pole is cut wedge-shaped at top, and the upper surfaces are well painted with linseed oil. In France the tops are cut to a cone and painted. In Italy the tops are rounded. In Norway, when barking the poles care is taken not to injure the layer under the outer bark, as the preservation of this adds to the durability of the poles.

There is considerable variation in the depth to which poles are inserted in the ground. The following are some additional examples:—Austria, 25 feet pole inserted 4·5 feet, the bottom of the hole being filled with stones. Bavaria 25 feet pole 5 feet, 31 feet pole 6 feet. Belgium, poles 21·3 feet to 29·5 feet are inserted 4·92 feet; poles up to 46 feet in length are inserted 6·76 feet, and poles 67·6 feet long are inserted 9·84 feet. England, poles are inserted to one-fifth of their length, but not less than 4 feet, nor in good earth more than 6 feet; in made earth they are inserted a foot deeper. Italy, poles 19·68 feet to 26·24 feet, inserted 1·20 metre (3·94 feet), this is increased in soft earth and decreased in rock. Denmark, poles 26·7 feet inserted 1·75 metre to 3 metres (5·74 feet to 6·56 feet). Norway, poles 23 feet to 26·25 feet, inserted about 2 metres (6·56 feet), more or less, according to nature of ground. In some places the ground becomes frozen several feet deep, and the thawing in spring would loosen the poles. Sometimes small stones are used round the poles, so that the latter are kept from contact with the surrounding earth; the object is to strengthen the line against violent storms. Holland, poles are inserted 1·50 metre to 2 metres (4·9 to 6·56 feet), according to size of pole and nature of soil.

Switzerland, poles 26·24 and 29·5 feet inserted 3·93 feet; 32·8 feet poles inserted 4·9 feet, stones are used to fill in round the poles.

In England poles are inserted a foot less in rock than in ordinary earth, or 3 to 5 feet; in Australia they are inserted 4 feet in rock; in Belgium only 1·97 foot; in Norway very shallow holes are made in the rock, and a truncated square pyramid of stone is built round the pole, lime mortar being used. The dimensions of this structure are 2·1 metres (6·79 feet) square at base, 1·5 metre (4·9 feet) at summit, and 1·5 metre (4·9 feet) high. In Italy poles are mounted with rammed earth, or earth and stones; the mound is conical and 0·5 metre high; in rock the holes are shallow, and rough masonry with lime mortar is used. The lines in the north of Germany, Denmark, and Norway, have to be built stronger than other European lines; the Norwegian lines are the strongest, the poles are closer, and inserted deeper than on other lines. In the north of Germany the wires may become encrusted with icicles to a thickness of 15 centimetres (6 inches); the weight of ice on one wire 60 metres (197 feet) span may exceed 3000 lbs.; although this limit is rarely reached, less extreme cases are frequent and sufficiently severe to try the supports.

Holes are commonly bored and dug, but in the case of large poles the difficulty of lifting the poles into bored holes without the use of shears is considered a great disadvantage; but it is contended, on the other hand, that by using a curved shovel to protect the sides of the hole while inserting the pole, shears may be dispensed with. In England the dug holes are stepped and made about 2 feet wide across, and 4 feet long in the alignment. In Austria and Belgium similar stepped holes are used. In Italy the holes are made only just wide enough at one end to admit the pole. In Denmark the holes are bored with an augur, this having proved cheaper, quicker, and stronger; the lines are found to bear storms well. Boring tools are used in England, and give satisfaction. In Australia, whenever practicable, the holes are bored with earth augurs, boring holes not less than 12 inches in diameter and 5 feet deep; when absolutely necessary the bar and shovel are used, but the excavation is not suffered to exceed 16 inches in diameter. Thirty miles of line constructed by the author in India was not damaged by a cyclone which took place just as the line was finished; the holes were 3 feet square, a large quantity of broken brick was placed in each hole, the poles had cross feet, and some of them were on made earth. The continuation of this line was damaged, the poles having been set with earth only. Poles set in large holes may be made to resist storms by the use of stones or bricks for filling the holes; but the expense must be greater, generally, than when small holes are bored or jumped. The use of boring tools is spreading, and of their general economy and utility there can be no room for doubt. Provision for a large number of wires is generally made in England by using higher poles, until the number of wires is so great as to render this difficult, when coupled and A poles are used necessarily. It is generally speaking preferable to provide for a large number of wires by using poles of the ordinary size, and using two separate sets of poles when the wires are too numerous, or the stress too great for one set. In France and Switzerland coupled poles are used on curves, as stated above; a large number of wires is provided for by using two poles coupled by iron rods, the poles being almost or quite parallel to each other. In Austria A poles are preferred, they are manifestly stronger. In Italy when the wires are too numerous for one set of poles, a second set is erected, the two sets being kept quite distinct, with a view to rendering total interruption less frequent. The use of exceptionally large poles is avoided as far as possible at crossings. The wires are sometimes divided into two sets, thus ordinary sized poles are

employed even with a very large number of wires. The wisdom of avoiding the use of very large poles is obvious; these poles are proportionately dearer both to purchase and transport, they are less generally useful, and from the greater liability to faults proportionately weaker. Bolt holes made for coupling poles should be carefully stopped with white lead or other suitable stopping to keep out water. When poles are planted on curves without ties, or with ties having no straining screws, it is a common practice to plant the poles a little out of the perpendicular, in the latter case they are drawn up when the wire is strained, but sometimes, *e.g.* in Belgium, the poles on curves are allowed to remain slightly so inclined even when tied. In France coupled poles are used to separate very unequal spans. Poles overloaded with wires so that they would be thrown down by high winds, are cross stayed—*i.e.*, two stays are erected to each pole extending at right angles to the alignment; this is applied in England to poles planted in made earth. In Belgium every pole on a railway line is stayed by a stay on the opposite side to the track, to ensure the pole falling clear of the rails in case of accident.

Iron Poles.—Several patterns of iron poles have been used in France experimentally. One pattern resembles the Morton pole; it is of galvanised iron, and has two longitudinal fins formed of the edges of the plates, through which the rivets pass the section; inside the fins is almost circular. When necessary, as at angles, the pole is strengthened by a triangular plate riveted into the longitudinal joint and projecting. The insulator brackets are bolted to the longitudinal fins, and a set of iron projections may also be fixed to these fins to form a ladder for climbing the pole. These poles are said to be cheap. A very simple iron pole is in use in Switzerland. This pole is simply a tube in one piece. The metal is ·197 inch thick, the lengths are from 2·55 metres (8·37 feet) to 7·50 metres (24·6 feet); the extremes are exceptional, and the limits are practically 3·45 metres and 5·70 metres. The poles are surmounted by points, the diameter below the point is 41 millimetres (1·6 inches); they are conical, so that a pole 5·70 metres (18·7 feet) long has a diameter at base of 75 millimetres (3·95 feet). These poles are fixed in pyramidal stone socles. When painted at intervals they are very durable, but they have proved inconvenient, because they could not be altered to carry additional wires. The mode of attaching the insulators to these poles is exceedingly simple; the insulator stalk is bent at a right angle, and the horizontal portion is put in a hole quite through the pole and fixed by a wedge.

Several engineers have designed poles of rolled iron bar of the forms of section most commonly employed in iron structures; of such poles a French pattern of T iron and a Bavarian pattern of I section are good examples. The French pole is simply a piece of T iron set in a moulded block of bèton. The bèton block is pyramidal or rather ⊥ shaped, its greatest horizonal dimension is placed across the alignment. It is strengthened by an iron band round its top, and has fifty to two hundred litres volume, *i.e.*, 1·77 to 7·06 cubic feet. The iron passes almost through the bèton block, and as a lightning conductor a wire soldered to the pole passes quite through. Bèton blocks are cheaper, stronger, and as they can be made on the spot, and of any suitable shape, more convenient than stone blocks. The cross-arms are square bar iron, 1·24 metre (4 feet) long, and 25 millimetres (·98 inch) square. They are passed through holes in the web, and bolted to the flange; each bar is fixed by two bolts, and carries four insulators. A T bar, weighing only about 5 lbs. per yard, and measuring only 1·38 inch in each direction, was found strong enough for a man to rest a ladder against, and to carry a No. 11 wire for a military line. When the earth is hard the

blocks may be dispensed with, and for military purposes a triangular earth plate may be used. In Holland bèton blocks have been used; these blocks are 1·25 metre (49 inches) high, and 0·45 metre (17·7 inches) square, their upper surfaces are inclined, and are perforated by a square hole 19·6 inches deep, slightly exceeding in tranverse dimensions the section of the pole. Cement is used to fix the pole. The Bavarian rolled iron poles are of I section, and 5, 6, and 7 metres in length. This form was chosen for the same reasons as it is generally used—viz., because the material is applied with the utmost mechanical advantage, and consequently at the minimum cost; the utmost economy was also desired in the fittings and fixture of the pole. The depth of the bar is 4·87 inches, width of flanges 2·94 inches, and thickness of web 1·3 inch. The cross-arms are of Γ iron bolted to the pole by bolts through the web; the angle iron is ·24 inch thick, and 1·81 wide each way. The insulator stalks have flanges; they are placed in holes in the cross-arms, and secured by nuts below. The poles are set in granite socles 4·27 feet high, and 1·39 foot square in section. The upper surface of the socle is inclined, and has a hole in it the shape of the section of the pole, and 9·85 inches deep. The pole is fixed by means of melted lead, calcareous cements having been found to crack in consequence of the vibration. Each pole is connected with the earth by a wire inserted in the lead used to fix the pole. A pole 16·4 feet long without cross-arms weighs 182 lbs. The flanged form is very economical, strictly it should taper upwards, but this is unattainable in rolled iron. The design of these poles and their fittings is an excellent one, but in most cases bèton blocks or iron base plates would be more economical than stone socles. In applying the flanged form to telegraph poles, possible lateral loads must be considered and provided for, and in general greater lateral stiffness is necessary than in ordinary flanged beams. The necessary lateral stiffness is given by making the flanges relatively wide, but the flanged form is in this respect obviously inferior to the box form. Several engineers have proposed to fix iron poles by driving or screwing them into the ground instead of placing them in holes previously bored or dug for their reception. Screw earth tubes were used in India for wooden poles and for some of the first iron poles, but their use has long been discontinued. Small military poles, invented by M. Lemasson, are tubes fitting together and fixed by screw clamps. The base is a steeled iron spike, it is driven into the ground by means of a large hammer, and the pole is then fitted to it. The Oppenheimer pole is the only pattern planted by driving which has been adopted for permanent lines. The base of this pole is 3 feet long, of a peculiar shape, somewhat like a triangular arrow or spear-head, with the corners rounded off; the material is cast iron, and the base is driven with its greatest width in the alignment. The upper part of the base has a socket to receive the end of the pole, this socket is filled temporarily by a suitably shaped piece of iron, the latter is covered by a rope pad, and the base is driven by a weight dropped on this rope pad. A light tripod, fitted with sheaves and a guide rod, is used to raise and drop the weight. After the base is driven the pole is fixed into it with cement, or preferably with iron wedges. These poles have a firm hold on the ground, the soil being compressed in erecting them. They are used on railways in Australia, and appear to have given satisfaction. The principle of driving the base is the only peculiarity in the design; if this feature prove satisfactory it might be applied to poles of other patterns above the ground line.

APPENDIX V.

EXAMPLES OF RIVER CROSSINGS.

SPANS.

Span across the River Kistna at Bezwarrah, Madras Presidency, East Indies.—Distance between masts, 5070 feet. The sites on which the masts are erected are 405 feet and 406 feet respectively above flood level. The wire is of iron, and has seven strands, each ·145 inch diameter. The poles are 14 feet long, 10 inches square, and set 4 feet in rock. *Insulation*:—Each end of the span wire is passed round a groove in a marble ball, or rather prolate spheroid, an iron strap passed round the ball in a groove in a plane at right angles to that of the wire fastens the ball to the post. To improve the insulation each post is boxed in, the wire passing through slits in opposite sides of the box. This mode of insulating the line has proved satisfactory.

Teesta River Span, Assam, East Indies.—2830 feet, masts 97 and 103 feet respectively. Wire, seven strand steel, each strand ·06 inch diameter; weight of rope 350 lbs. per mile, tenacity 26 cwts.

Kotree Span across the River Indus, East Indies.—Span 1950 feet; six wires, each wire seven strands, tenacity 33 cwts. Masts 143 feet 9 inches and 150 feet high, clear, respectively. Lower masts tripods of cast-iron tubes braced together, and fixed on sockets set 10 feet in masonry. The tubes are cast in lengths of 6 feet 3 inches, have flanges, and are bolted together. These tripods are 93 feet 9 inches and 100 feet high respectively. The top masts are wrought-iron tubes, and stand 50 feet clear of the tripods.

Span across the River Hooghly, near Barrackpore, Bengal.—Distance between masts 2135 feet. Masts 149 and 147 feet high respectively; difference of level 14 feet 6 inches. Headway 70 feet clear. Wires, ten in number, placed 2 feet 6 inches apart, and of steel, weighing 350 lbs. per mile. The masts resemble those of the Kotree span, described above.

Span across the River Ganges at Benares.—Distance between masts about 2900 feet. The site of one mast is about 3 feet above flood level, that of the other at about flood level. The masts are simple, and built up of pieces about 30 feet long. One mast is of Saul wood, the other is almost entirely of saul, the remainder being of teak. They are built only in length; the logs are joined by splices, each 6 feet long, and secured by three iron clamps 2 inches by 5 inches, tightened by bolts. The logs were not shaped, but used square, as purchased. Each splice is fitted with four stays anchored to the ground by large stones. The stays are of two strands of No. 1 B.W.G. wire, and those of alternate sets are in the same vertical planes, the anchors being placed at the angles of a regular octagon. The top stays were originally placed at an angle of 45° with the mast, and all the lower stays were anchored at the same distance; but the lower stays were afterwards altered and placed *parallel* with the upper ones. The masts are about 180 feet long, 16 inches diameter at base, and 5 inches at summit. It was originally intended they should be placed in pits 5 feet deep, a large slab of stone being placed in each pit for the mast to rest on, and the pit filled up with charcoal or other suitable material; but this was not carried out. Each mast stands on a stone slab in a pit, but the pit has not been filled in, nor is the foot of the mast otherwise fixed. Each mast was erected in two parts, the lower segment about 115 feet long, and the upper built of two pieces. The upper segments were used for rais-

ing the lower ones. The scarf between the upper segments has its surfaces cut at right angles to each other (Fig. 40) for convenience of fitting, the other scarfs have oblique surfaces (Fig. 41). The diameter at the scarf between the segments is 9 inches. The wires are two in number, of steel, No. 10 B.W.G., calculated dip 100 feet; the wire between the masts and terminals is iron, No. 5½ B.W.G. After the masts had been erected, and before the wires were up, a boat adrift fouled one of the stays, and broke off the top log at the joint. It was then decided to remove this mast. The mast was successfully moved on end with stays fitted just as it stood, to a new site 80 yards further inland, and 150 yards along the river. The removal of the mast only cost about £16, 10s., and as compared with taking it down and re-erecting it, there was a great saving of time and money. This will no doubt form a precedent for moving masts in future. The removal in this manner was devised and carried out by Mr. H. A. Kirk, the assistant superintendent in charge of the work. The work was finished in January, 1874. The masts are still standing, and are likely to prove very durable. The only point in which they appear open to criticism is the oblique scarfs used for joining the pieces. There would have been less sacrifice of strength if the abutting surfaces of the pieces had been cut at right angles to the pressure, and long iron fish plates or splints and through-bolts used, instead of the hoops or clamps. Although placing stays of the several sets parallel to each other improves the appearance of the structure, it is a sacrifice of mechanical advantage. The placing of the foot of the mast below the surface of the surrounding ground is essential to prevent possibility of disturbance of the foundation, unless an artificial foundation be carried down several feet. If the mast be buried there is a gain in strength due to the end being fixed; but if the earth is not filled in it is preferable to have an artificial masonry foundation brought up to the level of the surrounding soil.

Crossing of River Soane, Bengal.—This crossing consists of seven spans, six masts being erected in the river, and one on each bank. Of the masts erected in the river four are 70 feet and two 32 feet high, clear of the piers. The difference in height is to allow for the inequality of the spans; the masts for the shorter spans being lower, the height of the wire above the water is the same at the centre of each span. The bank masts are similar to those described in Article 332, page 230. They are made up of flanged tubes, trussed with iron rods and L iron street braces, and stayed with rod stays. Their heights are 119 feet and 83 feet clear respectively. The masts erected in the river are not stayed. These are erected on small piers of ashlar masonry, each pier resting on a foundation of two wells 30 feet deep. The piers are similar in shape to river bridge piers; they are erected at right angles to the current, and have a pointed cutwater at each end. Their dimensions are—length at bottom 12 feet 6 inches, greatest width 4 feet, height above wells 15 feet. The masts are in section of box form, the flanges or ribs being of plate iron, the double web of lattice work. The box form was preferred to the simple I, because stiffer laterally; and the lattice web was preferred to plates, because it affords facilities for painting and climbing. Cast-iron sole plates 5 feet × 3 feet are bolted on the top of the piers by bolts passing through the piers and secured to bars in the wells. The masts are secured to the sole plates by bolts, and this connection is further stiffened by triangular fins standing 4 feet high. The plate flanges are placed parallel with the line wires and across the river. The masts are square in plan, 18 inches square at base, and 6 inches at top. The insulator fittings are bolted to the projecting edges of the flanges. The spans are 2,340, 1,500, 1,500, 2,000, 1,500, 1,500, and 2,340 feet respectively; the conductors are of seven strand steel wire, weighing 450

lbs. per mile. The dip of the wire was checked by white lines painted on the masts; that of the centre span was verified by actual measurement. The stream has a very strong current, and rises and falls very rapidly; the spans were necessarily made unequal, to get the best available foundations for the piers.

American Spans of North-Western Telegraph Company.—The longest of these is upwards of 2,000 feet in length, and is across the Missouri. These spans are made of American compound wire. All factory joints are cut out, and the wire is joined by insoldered spring joints, described in the Appendix on wire. A solid joint in a long span of compound wire causes fracture. At each end of the span No. 9 iron wire is used, and this is continued for 20 or 30 feet over the stream to prevent the compound wire being used over the support where it would be damaged by chafage, &c. To allow of the wire being lowered during the cold weather when navigation has ceased, it is suspended from a pulley. Drawbridges are crossed by erecting high frames on the fixed portion and spanning the draw. As this cannot be done with a large number of wires, in this case a light iron tower is erected on the draw span, from the top of this tower a three-inch iron rod extends upwards with a collar on it every 3 feet; the cross-arms carrying the insulators are centred on this rod, rest on the collars, and are free on the vertical bar. The wires hold the cross-arms while the tower and rod turn with the bridge.

On another American crossing, in the Pacific coast system, a four-wire conductor cable was used. The specification was not obtained. The span was 3,600 feet.

CABLES.

Cables Connecting Vancouver's Island with Washington Territory (America).—Three sections, 6, 4, and 2 miles in length respectively. Conductor seven strands, each a pure copper wire, two layers gutta percha, $\frac{9}{32}$ thick, one layer machine banding, one layer tarred hemp guard, twelve No. 9 galvanised iron wires, laid spirally. Cable manufactured in San Francisco by the Construction and Maintenance Co. The bottom is bad and the tides very heavy; the average life of the cables has been about three years, excepting the crossing of 3,600 feet referred to above; rivers on the Pacific coast system are crossed by cables like that described above; the crossings are short.

The latest type of Indian river cable is across the Pudda, in Bengal. Length 3,290 yards, conductor seven strands, each a copper wire ·036 diameter, three layers gutta percha; total diameter ·32 inch; four layers tanned jute, and twelve galvanised iron wires, each ·254 inch diameter, between 3 and 4 B.W.G.—total diameter 1·224 inch, tenacity 18½ tons.

APPENDIX VI.

UNDERGROUND LINES.

THE systems of construction described (pp. 349, 382) are those in use in England and France principally. In most large Continental cities, the

number of wires being few, readiness of access to them is of less importance; permanent cables are therefore preferred to tubes, the wires in which may be changed. These underground lines are laid in multiple conductor cables of the type used for subaqueous lines. Each cable contains from five to seven conductors, insulated with gutta percha, and protected by iron wires. These cables are jointed and tested with the care bestowed on subaqueous lines, and once laid they are exceedingly permanent. They may be laid deeper than tubes, and hence better protected against deterioration. In Belgium, two or more of these cables are laid in a brick trough, the trough filled up with sand, and the whole covered with earth. This system is quiet successful. In Switzerland, cables are laid on the ground for crossing the mountains, where an aerial line would be liable to interruption from snow and ice. The longest and one of the most recently constructed underground lines is that between Berlin and Halle. This cable contains seven insulated conductors, each composed of seven copper wires 0·6 millimetre (·0236 inch) diameter. Each conductor is covered with two layers of gutta percha and two layers of Chatterton's compound,—viz., one layer over and betweeu the copper wires, the second between the layers of gutta percha. The thickness of each insulated wire is 5 millimetres (·197 inch). Tarred hemp is spun on to 17 millimetres (·669 inch). The cable is protected by sixteen galvanised iron wires of 4 millimetres (·157 inch) diameter; these wires close up completely against one another. This line is an experimental one; the design, although empirically chosen, has evidently been selected after careful consideration of what has already been done, and from the results obtained.

Mr. M. A. Holtzmann has been experimenting at Amsterdam on an original system. The insulating material is termed "brai" liquid, and is a residue from the distillation of coal tar. When cold, this material is a flexible solid, which has been found to be unchanged after having been buried ten years. Gutta percha soaked in a mixture of equal parts "brai" liquid and creosote was not apparently altered, but in case of doubt the gutta percha may be protected by tape saturated with a protective. The mode of construction consists in laying troughs of creosoted wood in a trench, filling these with melted brai liquid, and, when the liquid is cool enough, the wires, thinly covered with gutta percha, are laid in the trough and covered with a lid. It is claimed that absence of brittleness in the compound, and its chemical permanence, fit it for the purpose if it is buried sufficiently deep to ensure protection against great variations of temperature, and the lines cost only about half the cost of cables. This system is experimental, and has been tried for upwards of two years on 5,000 metres of 12-wire line (*Journal Telegraphique*). In Holland, the underground wires are laid in tubes of pasteboard and asphalt manufactured at Hamburg. The system was invented by M. Jaloureau. It was commenced experimentally, in 1865, by laying a line of 2,580 metres in Amsterdam, and the experiment has been followed by great extension of the system, and its adoption by the Netherlands government. The tubes are in lengths of 7 feet, and are used of 2 and 3 inches diameter. They are joined by abutting their ends, covering the joint with a short segment of tube to fit, and cementing with bitumen applied hot. The material employed becomes very fluid when heated, and very strong when set. The ease with which the work can be carried out, the fact that the tubes are hermetically sealed, the cheapness of the materials, and facility of transport, are in favour of this system. The largest number of wires placed in a 3-inch tube is 40. In the English system as many as 72 wires are placed in a 3-inch pipe, and 128 in a 4-inch. Portland cement is used in England to cement the pipes together, as well as

clay, lead, and yarn; but in any case a stopping of yarn or tow is applied first, to prevent any of the cementing material falling into the pipe.

In America, for the Western Union Co., tubes are being used for the underground lines; in New York city and Philadelphia the wires will soon be necessarily laid underground. Two new systems are being tried in America, the particulars of which have been supplied by Mr. C. H. Haskins. A New York manufacturer of glass-lined water pipes has invented one system, the other is the invention of Mr. David Brooks. In the first system a cluster of glass tubes, embedded in paraffin, is inserted in a wrought-iron pipe; at the joints the ends of the tubes, ground flat, are placed together with coupling plates. There is a groove in the face of each coupling plate, and, after the plates have been bolted together, this groove is filled with a water-tight preparation. Naked wires are used, drawn through the glass tubes. All the wicket-gates of the Centennial Exhibition are connected with the treasurer's office by this means, and communication has never been interrupted. In Mr. Brooks' system a tube is laid, in the usual manner, with small flush test-boxes at the street corners, &c., a cable covered with hemp saturated with paraffin is drawn in, nearly filling the tube; paraffin oil is then forced in, and leakage is compensated by pouring in oil at the test-boxes.

The practice of making the insulated wires up into cables by binding them together with tape or yarn has been discontinued in England, because the tape rotted and obstructed the tubes; but a tape covering saturated with Stockholm tar is used over each wire. If tape be used, cotton tape, being more durable than hemp, should be preferred. Hooper's Telegraph Works Co. manufacture a core covered with a braided covering of flax yarns, the whole being saturated at 280° to 300° Fahr. with a special compound. The yarns are spun on in the same manner as the catgut on a riding-whip; the compound is a brown, waxy material. The preservative enters the felt covering of the core, particularly in the thicker sizes, and, if itself chemically permanent, the great utility of such an air-tight covering cannot be doubted. Core so protected is stated by the manufacturers to be reliable "when partially submerged and partially exposed to the air," and it appears likely to prove more durable for underground lines than the thinly covered gutta percha core commonly employed. This kind of core is being used in England as field telegraph wire, and some has been supplied to the English Postal Telegraph Department. The French government lines are of gutta percha covered wire protected by tape. The conductor has four strands; it is covered with only one layer of gutta percha to ·2 inch diameter. The gutta percha is covered by two layers of cotton tape, previously treated with sulphate of copper solution as a preservative; the inner layer of tape is tarred with Stockholm tar. The covered wires are made up into cables containing from three to seven conductors. The lines are laid in cast-iron tubes, made in pieces 8 feet 2 inches long; the joints are leaded, and every 50 metres a section of pipe of a larger diameter is fitted so that by sliding this section along the main tube, access may be obtained to the cable. The joints at these places are also stopped with lead, so that the tube is sealed and the cable protected against the infiltration of water or gas.

APPENDIX VII.

DEEP-SEA SOUNDING WITH PIANOFORTE WIRE.

THE following mode of sounding, devised by Sir W. Thomson, has been employed in several important cable-laying expeditions, adopted (somewhat modified) by the American navy, and is being generally adopted. The wire used is pianoforte wire of the best quality, about 22 B.W.G., weighing 14½ lbs. per nautical mile, and bearing 230 to 240 lbs. tension without breaking. The wire cannot be joined by soldering, as it is then liable to break at the joint. It is spliced as follows:—The ends to be joined are slightly warmed and coated with marine glue for about 3 feet, to promote surface friction; the ends so prepared are laid together, forming an overlap of 3 feet, and from the centre of the splice the end of each wire is wound round the other in a long spiral, having one turn per inch, the ends are then tightly served with twine. This joint does not weaken the wire as would a stiff-soldered joint, wire ligature, or short twisted splice, and it is easily made in a few minutes. The wire is made in lengths of about 200 yards. To the outer end of the wire is fastened a galvanised iron ring, weighing about half a pound; to this ring is attached about 5 fathoms of hemp line, to the end of which is attached the sinker. The iron ring serves two purposes—viz., that of a coupling between the hemp line and the wire, and of an auxiliary sinker to keep the wire tight when the sinker rests on the bottom. The hempen line is inserted that it may coil on the bottom; because if the wire were continuous to the sinker, and permitted to coil on the bottom, it would become kinked. The sinker is of lead, and for depths not exceeding 3000 fathoms under ordinary conditions, weighs 30 to 35 lbs. For 4000 fathoms or more, the inventor thinks it would probably be found desirable to use a sinker weighing 100 lbs., with an appliance for detaching it on reaching the bottom. In the American navy the practice of detaching the sinker is adopted more generally, not only for great depths.

The sounding machine may be divided into two parts—viz., that for letting the line out and controlling its motion while running, and that for hauling the wire in after the bottom has been reached. The sounding wheel is of thin galvanised sheet iron, made as light as admissible, in order that when the weight touches the bottom the inertia of the wheel may not cause an excess of wire to be run out coiled on the bottom, and consequently kinked. The circumference of the wheel is one fathom, with a correction for the increased diameter due to the wire wound on it. This wheel is fitted with a very simple brake, its framing is movable on a slide, elevated above the deck, and projecting over the taffrail, that the wheel may be readily run horizontally on board and out over the taffrail as required. The sounding line is preferably let out over the stern. The brake consists of a rope passed round the circumference of the sounding wheel. This rope is fixed at one end and weighted at the other, consequently it presses on the circumference of the wheel. The rate of change of pull of such a cord per radian (*i.e.*, angle whose circular measure is unity) round the wheel is equal to the amount of the pull at any point multiplied by the co-efficient of friction; the whole tangential resistance which the cord applies to the circumference of the wheel is equal to the excess of pull at one end above that at the other end of the cord. The apparatus for hauling in the sounding line consists of a castor pulley projecting over the taffrail and an auxiliary pulley. The castor pulley is the same in principle as the castors fitted to furniture, and

is so fitted that when the ship rolls the plane of the pulley remains vertical; this is also assisted by a counterpoise. The wire is passed over the castor pulley in hauling in. If the ship rolls, this pulley accommodates itself to the wire; if the ship drifts laterally, so that the wire streams to one side, the pulley takes an oblique direction. Thus this appliance renders it practicable to haul in the line when the ship is rolling heavily or drifting. The auxiliary pulley is used for hauling in the wire and taking the strain off the sounding wheel. If the wire were raised directly by the sounding wheel, the pressure on that wheel would be enormous; for if the tension on the wire be 50 lbs., each turn of wire would compress the wheel at the two ends of any diameter with a force of 100 lbs., and this being the effect of each turn it would be multiplied by the number of turns. The interposition of the auxiliary pulley prevents this pressure to any required extent. The auxiliary pulley overhangs its bearings, so that one or two loops of wire may be put round its edge. This pulley being turned in the proper direction by two handles worked by men, or by a band hauled on by men, or driven by an engine, hauls in the wire, which, as it leaves this pulley, passes on to the sounding wheel again. The assemblage of parts described above—viz., the sounding wheel with brake, wire, and sinker, the castor pulley, and the hauling in pulley—constitute, with suitable framing, a simple sounding machine. The castor and auxiliary pulleys are placed lower than the sounding drum, and when hauling in the sounding drum is drawn on board on its slides and placed over the auxiliary pulley.

When a sounding has to be made, the sounding wheel is run out on its slides over the taffrail, the sinker and hemp line attached, and the weight dropped. By means of the brake a measured resistance, more than sufficient to balance the wire out at each moment is applied to the drum; as the wheel revolves the person in charge watches a counter which registers the number of fathoms or turns of the wheel, and he adds for every 250 fathoms such a weight to the brake cord as shall balance, by its resistance to the wheel's motion, the weight of the additional wire. Hence the resistance on the wheel is always more than the weight of the wire out. The force with which the weight reaches the bottom is less than that due to the full weight of the sinker in water; when the sinker reaches the bottom the wheel is pulled in one direction by the weight of the wire only; but this being more than counterbalanced by the brake resistance, this resistance acts to stop the wheel when the bottom is reached, and to prevent the wheel flying round by its inertia. In fact, the effect of this arrangement is to feel the bottom, and the wheel stops almost immediately the bottom is reached, not running on more than one turn at most. To take an illustration:—For a depth exceeding 1000 fathoms, 3000 fathoms is considered a convenient length to put on the wheel; this length weighs about 43 lbs. If the depth exceed this, then a second length on another wheel is spliced on to the first, this operation taking about two minutes. The lead weighs 34 lbs., and the resistance put on the drum by means of the brake is kept 10 lbs. in excess of the weight of wire out; thus only 24 lbs. of the weight of the sinker acts as moving force. As the wire runs out, for every 250 fathoms or turns of the wheel the brake resistance is increased by 3 lbs., the weight of 250 fathoms of the wire in water. When the sinker reaches the bottom its weight is taken off the line; but as 10 lbs. of this was balanced by brake resistance, this resistance stops the wheel within one turn, and the bottom is felt in as great a depth as 4000 fathoms. The stoppage of the wheel is almost instantaneous under these conditions. After the bottom has been reached, which is known by the stoppage of the sounding wheel, the sounding line is held up by two men with thick leather gloves, or better, by a spun-yarn stopper. This relieves

the wheel; a little more wire is unwound, and the wheel with its bearings is run on board on its slides; the wire is then passed round one quarter the circumference of the castor pulley and three quarters of a turn, or one turn and three quarters round the hauling-in pulley, the latter is turned by two or four men, and the wire is wound on the sounding wheel simultaneously by one or two men working on handles fitted to its shaft. The auxiliary pulley takes from two-thirds to nine-tenths of the strain of the wire off the sounding wheel. On board the cable S.S. "Faraday" the hauling-in is effected by a steam winch.

The bottom is reached at a depth of 2,000 to 3,000 fathoms in thirty to fifty minutes. With 3,000 fathoms of line out, probably 400 feet per minute is a safe speed for hauling in; the last 1,000 fathoms may be easily and safely got in in seven or eight minutes. To attain these speeds more men than the numbers stated above would have to be employed, and a mechanical appliance for increasing speed, or a donkey-engine, may be used. In a heavy sea the rate of hauling must be slower. An arrangement proposed by Professor Jenkin can be readily applied, by which the men or engine may haul in as fast as they please, and yet be unable to put more than a certain tension on the wire, the line coming in fast when the strain is easy, and not at all when the ship is rising and producing such a pull that, if hauled upon at all, the wire would break. With twelve or fourteen men hauling on a multiplying arrangement, the 34-lbs. sinker may be got in from a depth of 2 miles in fifteen minutes. With a heavy sinker (100 to 150 lbs.) and detaching apparatus, the sounding might be taken with only about twenty minutes' detention of the ship. A sounding in 1,000 to 1,500 fathoms, with recovery of sinker, may be taken with detention of the ship for fifteen to twenty minutes, while the lead is going down, and then going full speed a-head. For flying soundings to 200 fathoms the speed of the ship is reduced to 4 or 5 knots for the sinker to reach the bottom, and then increased up to full speed. Under these conditions a boy can haul in the line with a 34-lbs. sinker from 150 fathoms, and it may be hauled on from 200 fathoms with ease by one man or by two men. With 3,000 fathoms of line out it will be generally found convenient to keep the ship hove-to while hauling in; with 2,500 fathoms, or less, the ship may be driven slowly a-head with increasing speed; with 1,500 fathoms out the ship may be safely driven a-head at 5 or 6 knots, and the last 500 fathoms may be taken in with ease and safety while the ship is going a-head at the rate of 10 to 12 knots.

The wire, when not in use, is preserved by immersion in a solution of caustic soda. In the American modification of the apparatus soldered joints are used to join the wire, a stronger sounding wheel is used, the weight is detached at the bottom, and the hauling-in pulley is dispensed with. The preservative used is oil, as caustic soda would attack the solder.

The advantages of sounding with wire over the ordinary method are—Very great saving of time, very great saving of labour, great facilities for taking flying soundings, it being unnecessary to detain the ship as by the old method—*e.g.*, flying soundings may be taken in from 100 to 200 fathoms with the ship going 4 to 5 knots. The sinker is saved and specimen of bottom obtained when this would be impracticable by the old method. Many of the practical difficulties of deep-sea sounding are removed, and soundings may be taken under conditions which, under the old method, would have rendered sounding impracticable, or the results inaccurate—*e.g.*, under the old method, when a long length of cord is out the lateral friction between the cord and water is so great that the pull of the lead is neutralised, and the ship must be kept over the line for hours to let it out and haul it in, not only is the detention considerable, but in a current it is very difficult to keep

the ship over the line. The machine is very simple, and therefore not costly. It is used in the "Hooper" and the "Faraday," and its use on cable ships will be general, the facility with which flying soundings may be taken during the laying of a cable being of the greatest importance.

In flying soundings the true depth is estimated. The following formulæ are useful:—If l=length of line out, a=horizontal distance travelled by the ship less horizontal distance travelled by sinker in reaching the bottom, the true depth, where the lead touches the bottom, is greater than $l-a$ and less than $\sqrt{l^2-a^2}$. For flying soundings within 200 fathoms, taken with the ship going 4 to 6 knots, the strict adjustment of the brake resistance described above is impracticable; in this case the resistance is fixed at from 5 to 10 lbs., a sudden decrease in the speed of rotation of the wheel indicates when the bottom is reached, and the wheel is then stopped by hand.

APPENDIX VIII.

TEMPORARY LINES.

The following are the general results of the experience gained during the Abyssinian, Ashantee, and Looshai expeditions, the Franco-German war, the famine in Bengal, and the autumn manœuvres in England.

Ground Wire.—For short lengths required to be laid rapidly and to be used for a short time only, india-rubber covered wire is generally employed. This may be laid on the surface of the ground, buried in a shallow trench, or it may be laid on the ground where admissible, and raised on poles or buried at road crossings, and raised on poles at river crossings. The arrangements for paying out and picking up the wire at a trot by the use of horses and mechanical appliances are practically useless; the wire has to be laid and taken up by hand. The india-rubber core is usually protected by hemp coverings, tarred or saturated with a special compound. A soft copper conductor, as used in submarine cables, has been found in practice too weak for ground wires for military temporary lines; the addition of iron or hemp in the usual way to give great additional tenacity is obviously impracticable. To obtain additional tensile strength, Major Mallock proposed the use of a compound conductor consisting of one pure copper wire surrounded by six soft iron wires, in lieu of the pure copper conductor. It is stated that wire of this kind has been adopted in the Italian army. An experimental waggon load (3 miles) was ordered for the British army, and a length of one mile was favourably reported on by a committee appointed for the purpose. The following figures show the relations between the old pattern (copper conductor) and the new (compound conductor):—

	Old Pattern. Copper Conductor.	New Pattern. Compound Conductor.
Tenacity, ...	125 lbs.	375 lbs.
Weight, per mile, . . .	282 ,,	285 ,,
Conductivity (relative), . .	2 ,,	1 ,,

Diameter of new pattern slightly less than that of old.

The committee found the new wire might be safely used for spans of 330

yards, and might be drawn well up; but the old pattern could not be raised off the ground over so long a span.

The following is the specification:—

Conductor, one tinned copper wire, diameter ·0135 inch, conductivity 90 per cent. that of pure copper, surrounded by six wires of best soft iron, diameter of each ·0135 inches. Insulator, one layer of vulcanised india-rubber to ·176 inch diameter. Protection, one spiral layer tape, and one braided covering of best Italian hemp, drawn through compound. Diameter of complete cable, maximum ·35 inch. Insulation 100 megohms per mile. Conductivity, maximum resistance 40 B.A. units. Tenacity about 450 lbs. The somewhat lower conductivity is of little consequence, as the wire is used in short lengths. In dry weather local faults in the dielectric are of little consequence in a ground wire, bare places even cause no inconvenience. When the wire has to be buried, as in crossing a road, it has been suggested that it be inclosed in a piece of india-rubber tubing. This was tried by Captain Lambert, and with markedly beneficial results.

For lines required to be more permanent and of greater length than those for which ground wire is suitable, light wire, supported on light poles or trees, is used, permanent lines, when present, being used as far as practicable. The wire generally used is of iron, and thinner than that used for permanent lines. For the Looshai expedition the wire used was No. $9\frac{1}{2}$ B.W.G., weighing 300 lbs. per mile; No. 16 copper wire was used for temporary connecting lines. In the Abyssinian and Franco-Prussian campaigns copper wire was used. In the first case the wire was exceedingly pure copper, No. 16 B.W.G.; although spans of 200 to 300 yards were practicable, the wire stretched, particularly when the poles were shaken. During the Franco-Prussian campaign it was found necessary to use forty poles to the mile with copper wire. The temporary lines used during the Ashantee campaign were No. 11 iron wire, weighing 3 cwts. per mile, and this proved excellent for the purpose. A stranded wire of three No. 18 wires has been suggested as nearly as good as one No. 11, and a half hundredweight lighter per mile. A good homogeneous stranded wire would no doubt prove suitable. A homogeneous wire was tried in Abyssinia, but failed; it was used for 20 miles, and the wire appears to have been bad in quality. Major Mallock proposed a compound stranded wire, the same as described above, for ground cable, he having found that six iron wires round a central copper wire is almost as strong as if the centre wire were also of soft iron. This wire has the following advantages:—Conductivity, $\frac{13}{7}$, and weight $\frac{50}{49}$, that of iron of same size; hence for equal conductivity the weight of compound wire is only $\frac{5}{9}$ that of iron wire. American compound wire has been proposed. As compared with No. 11 B.W.G. iron wire, the weight of American wire is only $\frac{13}{40}$. A simple joint might be devised for temporary lines. The only objection to this wire is its stiffness, which would be inconvenient when rolling it up and running it out. The fact that compound wire is more readily corroded than simple wire, is of no importance in the case of a temporary line.

Insulators.

Insulators may frequently be dispensed with; the necessity for their use depends on the nature of the supports, the climate, and the time the line has to stand. In the Abyssinian campaign no insulators were used; old seasoned bamboos were used as supports, and Major St. John thought them as good as porcelain insulators, unless rain was running down them. In Bengal the

lines erected were 541 miles long, and a year's experience was gained. No insulators were used, and it was found that bamboos, in open ground exposed to the sun, remained sufficiently clean for one monsoon; but when the poles were under trees and constantly in the shade, they became covered with a kind of spongy mildew, the presence of which was fatal to insulation. On the Abyssinian lines no difficulty was experienced in working over 100 miles without relays. When the wire has to be fixed to living trees, insulators are necessary. In the Looshai and Ashantee expeditions insulators were used; small porcelain insulators gave complete satisfaction. In the latter case some ebonite insulators were used; they were defective, split occasionally, and proved very unsatisfactory. The field insulator used in India is simply a smaller pattern of the porcelain line insulator; it can be spiked to a living tree, to rock, or bound to a small tree or bamboo by wire serving. Its breaking strain is 3 cwts., its resistance 2,000 megohms, and it can be used with No. 9 wire. Spiking and binding are the usual means employed for fixing insulators, but in the Ashantee campaign they were fixed into the top of the bamboos as follows:—The bamboo was cut off level 6 inches above a ring, a serving of No. 11 wire was put round it to prevent it spliting, and a plug of soft wood was driven into the bamboo to fill it, the insulator stalk was then inserted in an auger hole made in the wooden plug. In Abyssinia the wire was simply put into a slit about 6 inches deep, cut across the bamboo pole, and it was turned two or three times round the end of every second or third pole. The experience of the Bengal famine lines indicates that the best kind of insulator for use with double bamboo supports (shears) is a hanging insulator, suspended from where the bamboos cross.

SUPPORTS.—When no timber is available near the spot, or the line has to be taken over hills up which poles would have to be carried, or, in fact, whenever poles must be carried long distances, light iron tubes packing into each other, or other form of iron pole, may prove economical and efficient; but when bamboos or other suitable wood can be obtained readily it is generally preferable. The bamboos for the Abyssinian campaign were sent from Bombay, and no doubt proved cheaper and more useful than iron poles would have done, as with the latter insulators would have been essential. As far as possible, living trees should be used as supports when available on the route. This was done to a great extent in the Ashantee and Looshai expeditions. In the Abyssinian and Ashantee expeditions single bamboos were used as supports in the open. On the Bengal famine lines each of the supports was of two bamboos, tied together near the top with wire, and then opened at the bottom like shears; the lower ends of the bamboos were placed 9 feet apart, and inserted 18 inches in the ground. On the Ashantee lines single bamboos were used, planted 60 to 90 yards apart, and inserted 2 feet in the ground; stones were used to make the hold on the ground firmer. On the Bengal lines it was found better to use three bamboos in the form of a tripod at each angle. When single bamboos or other light poles are used the angles must be tied. The ties are usually of wire, and attached at the lower end either to pickets inserted in the ground or to buried stones. On the Ashantee lines wire ties and pickets were used.

The light wire used for temporary lines is usually stretched by hand, tackle being superfluous. For working temporary lines it is generally considered better to use full sized instruments than small portable instruments; the instruments forming so small a proportion of the weight to be carried, the additional weight of the full sized instruments is inappreciable, whereas the small instruments are more troublesome to use. The lines not being constructed so strongly as permanent lines, having a higher resistance and

frequently inferior insulation, a reliable and sensitive instrument is a necessity. The batteries used are required to be portable and readily prepared for use. On the Bengal lines, which differed in many respects from military lines, the ordinary Minotti battery was used; this battery could not be used for military lines. The Ashantee lines were worked with the Leclanché battery; the Marie Davy battery was used in Abyssinia and during the Franco-Prussian war; both these batteries proved satisfactory. The objection to the former is that it cannot be repaired excepting at the manufactory; the other has not this defect, if a supply of spare porous cells be supplied, and it is therefore preferred. When stores and labour are available, temporary lines may be put up very quickly; the difficulties which have been most felt are want of labour and transport. In Bengal 541 miles of line were erected, and thirteen offices opened in thirty-five days, including the purchase of bamboos. On one occasion an officer put up 31½ miles in two and a half days, he having to purchase the bamboos and supervise the distribution and construction.

APPENDIX IX.

ADDITIONAL DATA.

The following data were accidentally omitted from the body of the work. Such data are frequently stated as if they had a fixed value; in these cases the values are merely averages. The values given below are merely approximations sufficiently near for most practical purposes. When the quantities are very large, or other circumstances render a close approximation necessary, specimens of the materials to be used should be weighed and measured.

	Weight of 1 cubic foot in lbs.
Dry timber, Fir of different kinds, Elm, and Chestnut,	30 to 44
Beech and Birch averages	43 to 44·4
Oak,	43 to 62
Indian Teak,	41 to 55
Saul and African Teak average about	60
Brick,	125 to 135
Brickwork, dry,	112
Masonry,	116 to 144
Sand, dry,	88·6
,, damp,	118
Clay,	120
Mud,	102
Granite,	164 to 172
Limestone,	169 to 178
Quartz,	165
Sandstone,	130 to 157
The above are adopted from Professor Rankine, after comparison with other authorities.	
Hemp as ordinarily applied in serving, Russian or Italian, about	39
Russian, Tarred.	56

	Weight of 1 cubic foot in lbs.
Manilla,	41
Hemp,	77
,, tarred,	111
Hooper's Material,	73·50
The above are taken from Clark and Sabine's *Electrical Tables.*	
Paraffin,	54·25 to 54·38
India-rubber,	57·3 to 58·74
(Messrs. Clark and Sabine give 56·44.)	
Ebonite about	81·7

The heaviness of some kinds of wood (dried) may vary upwards of 100 per cent., and any material having an organised structure, like hemp and wood, must vary considerably in heaviness. Sand must vary in heaviness according to the size of the grains, and mud according to the quantity of water held in it. Average values are only averages of certain measurements made and recorded; their use is simply to make rough calculations where great accuracy is unnecessary or unattainable. These remarks may appear unnecessary, but the frequency with which absolute values of this kind are given justify them. Not only are fixed values given, but these are given to two places of decimals—*e.g.*, Teak, oak, and mahogany are stated to weigh 46·56, 60·62, and 53·25 lbs. per square inch. It is not apparent how the writer arrived at such figures; and whether they are averages of Indian and African teak, every European variety of oak, and of Honduras and Spanish mahogany; in any case they can be of but little practical utility, and may mislead.

ADDENDUM TO ART. 180, PAGE 105.

Wind or Water Pressure.

The intensity of wind pressure on a cylindrical surface has been stated as equal to about half that on a plane surface equal in area to the plane projection of the cylindrical surface. This estimate, given by the best authorities, on consideration of the following will be seen to be incorrect:—

Let the pressure of a current of wind or water on a plane surface of unit area, placed at right angles to the current, be $=P$. If the plane surface be inclined to the current, the pressure on it will be less than P. If it be inclined so that its edge be presented to the current, the pressure on it will $=0$, hence the pressure on a plane surface varies between P and 0 according to its inclination to the current. For simplicity, imagine the current horizontal, and the plane acted upon vertical. The current force acting on the inclined plane may be resolved into two components, one in the plane, the other at right angles to it; the former exerts no pressure on the plane, the latter is obtained by multiplying the current force by the cosine of the angle between the plane and a plane at right angles to the current. If the latter component, found as above, be now again multiplied by the cosine of the above angle, the product will be the pressure exerted by the current on the inclined plane in terms of P, the pressure it would exert on a plane at

right angles to its direction and equal in area to the projection of the inclined plane. Hence, the pressure on a surface inclined to the current is the product of P and the square of the cosine of the plane's inclination. Suppose a solid body exposed to the current, the section of the body being a triangle, and the apex of the triangle presented to the current, the limits of pressure are P and 0. If the third side of the triangle be at right angles to the current, the pressure on each of the other sides varies as the $\cos^2$ between the side taken and the third side, and $\cos^2 P$ represents the pressure on a unit surface. Hence the sharper the edge presented to the current the less the resistance to the current. From the above may be calculated the pressure of a given current acting on a body whose horizontal section is a triangle; this pressure is manifestly equal to $P . \cos^2 \times$ area exposed on each of the planes presented to the current. The above is true of a cylinder, each point of the cylindrical surface being assumed coincident with the tangent at that point; but in this case the angle varies constantly and is not fixed, as in the case of the triangular prism. On the cylindrical surface the pressure varies between P at the most prominent point and 0 at the extremity of the diameter of the section drawn at right angles to the current direction. At any intermediate point the pressure is $P \times \cos^2$ as before, and the sum of the pressures at all points is $= \frac{2}{3}P$. In the above the effects of friction and adhesion between the particles of the fluid in motion have not been considered, hence it is manifest the above values are too small for practical application. The friction between water and an immersed body varies with the nature of the surface of the latter and the square of the velocity of the current. Hence if the triangular prism described above had its presented angle sharpened and its sides prolonged, a point would be reached at which the friction against the sides would counterbalance the diminution of resistance consequent on the greater sharpness of the presented angle. As a matter of fact the resistance of a cylindrical body to a current of water has been found in practice to be about $\frac{3}{4}$ P instead of $\frac{2}{3}$ P indicated by the above formula. The resistance to a current of air is between $\frac{2}{3}$ P and $\frac{3}{4}$ P.

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